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Clayton et al.

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(54) **INSTRUMENTED ITEM HOOK SYSTEM**

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(52) **U.S. Cl.**
CPC ***G06Q 10/087*** (2013.01)

(58) **Field of Classification Search**
USPC 705/28; 211/85.29
See application file for complete search history.

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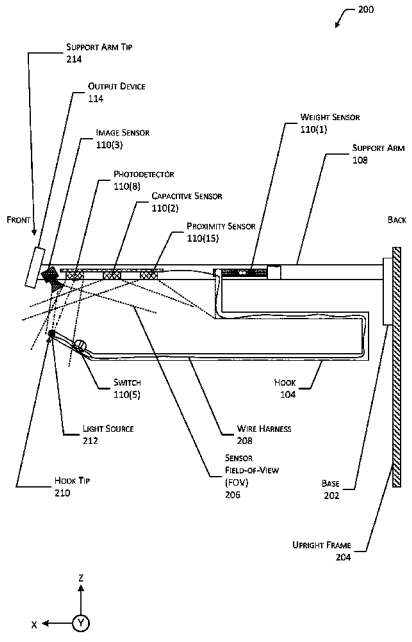
(57) **ABSTRACT**

Items may be stored at an inventory location using an instrumented hook system. The instrumented hook system may include a hook from which items may be suspended. The hook may be affixed to a support arm using a weight sensor. The weight sensor provides weight data indicative of the weight of items suspended by the hook. The system may also include other sensors such as capacitive sensors, photodetectors, image sensors, and so forth. Sensor data from these sensors may be used to determine interaction data indicative of a quantity on hand, quantity picked, quantity placed, and so forth.

20 Claims, 10 Drawing Sheets



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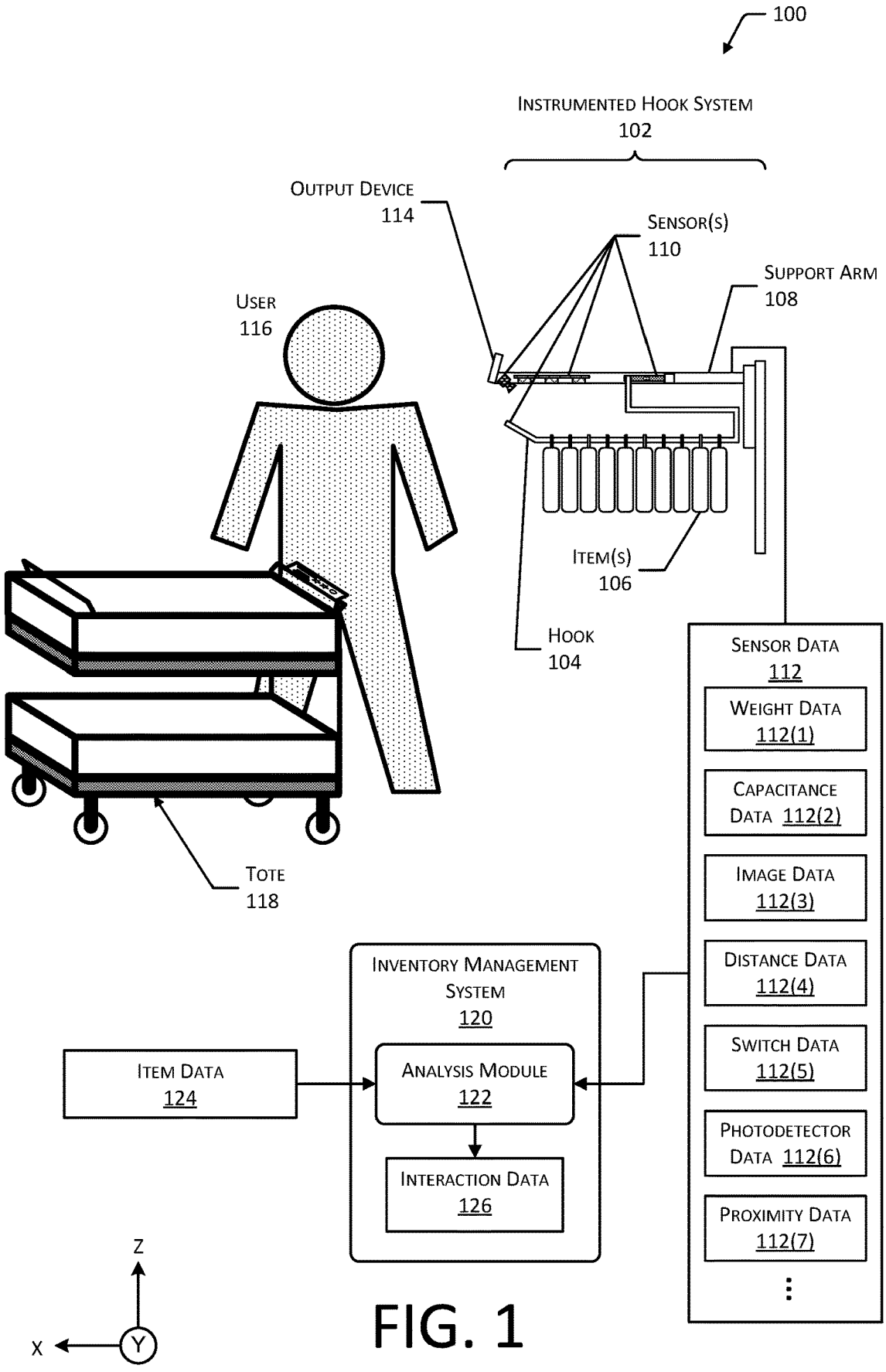

100
INSTRUMENTED HOOK SYSTEM
102
OUTPUT DEVICE
114
SENSOR(S)
110
SUPPORT ARM
108
USER
116
ITEM(S)
106
HOOK
104
TOTE
118
SENSOR DATA
112
WEIGHT DATA
112(1)
CAPACITANCE DATA 112(2)
IMAGE DATA
112(3)
DISTANCE DATA
112(4)
SWITCH DATA
112(5)
PHOTODETECTOR DATA 112(6)
PROXIMITY DATA
112(7)
INVENTORY MANAGEMENT SYSTEM
120
ITEM DATA
124
ANALYSIS MODULE
122
INTERACTION DATA
126
Z
X
Y

FIG. 1

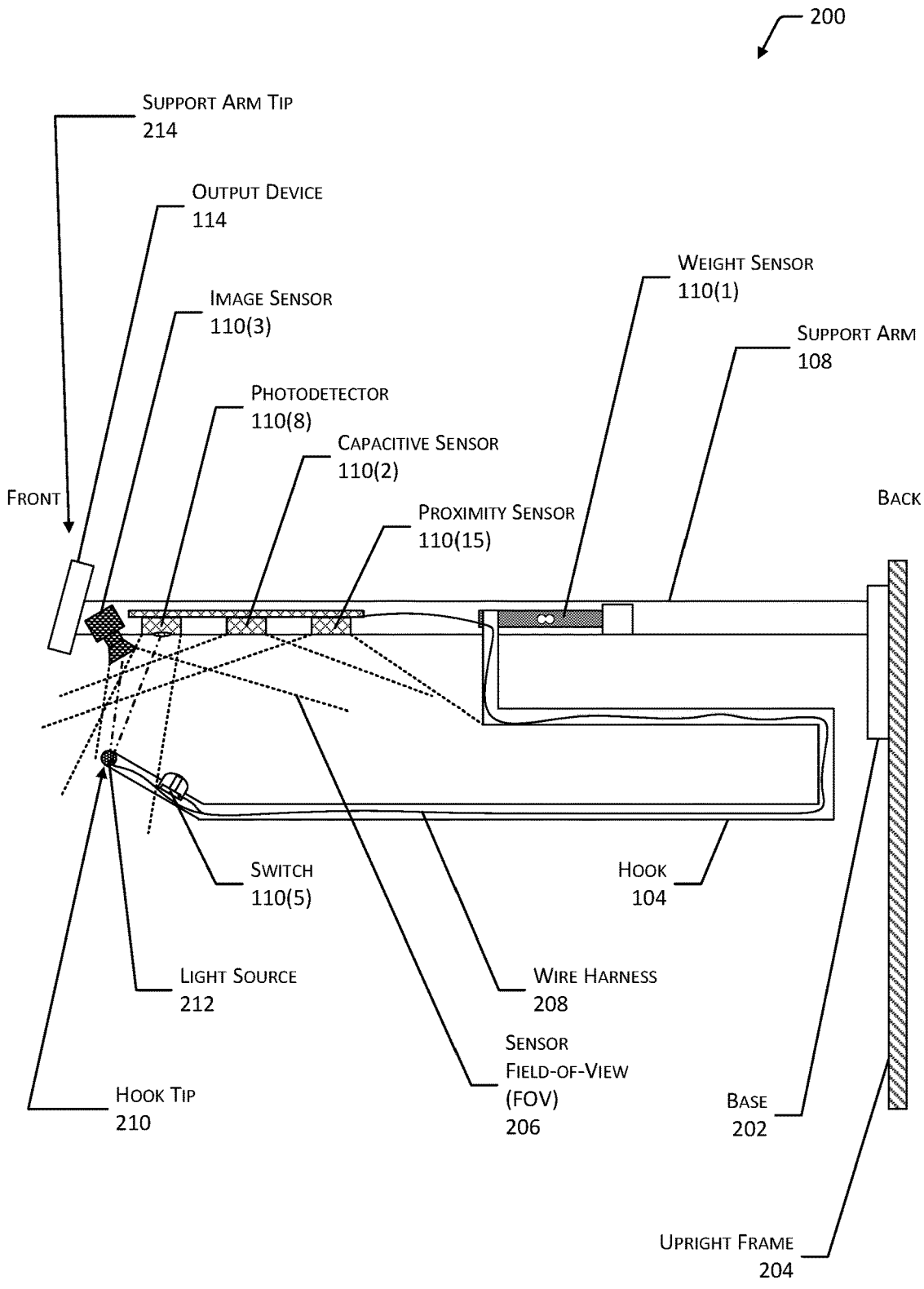
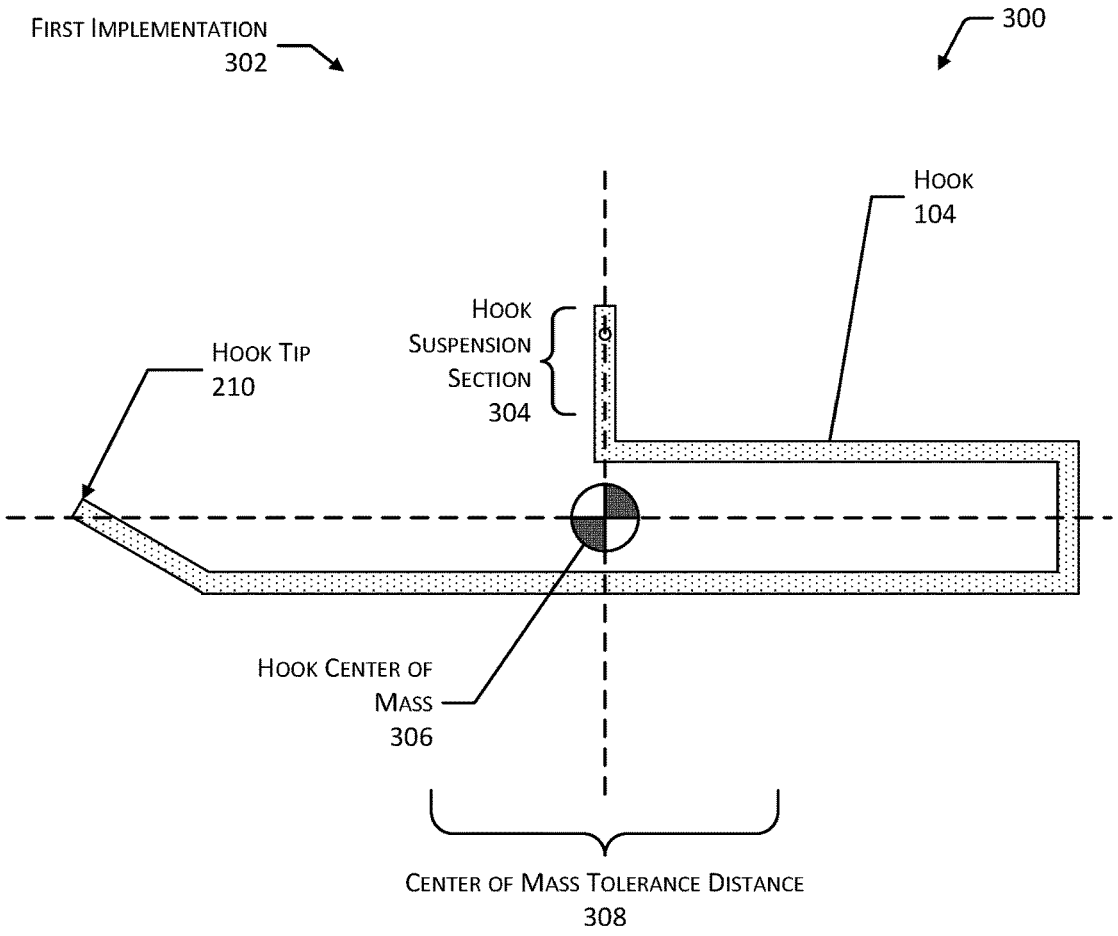

200
SUPPORT ARM TIP
214
OUTPUT DEVICE
114
IMAGE SENSOR
110(3)
PHOTODETECTOR
110(8)
CAPACITIVE SENSOR
110(2)
PROXIMITY SENSOR
110(15)
WEIGHT SENSOR
110(1)
SUPPORT ARM
108
FRONT
BACK
SWITCH
110(5)
HOOK
104
LIGHT SOURCE
212
WIRE HARNESS
208
SENSOR
FIELD-OF-VIEW
(FOV)
206
HOOK TIP
210
BASE
202
UPRIGHT FRAME
204
Z
X
Y

FIG. 2


FIRST IMPLEMENTATION
302
300
HOOK
104
HOOK
SUSPENSION
SECTION
304
HOOK TIP
210
HOOK CENTER OF
MASS
306
CENTER OF MASS TOLERANCE DISTANCE
308

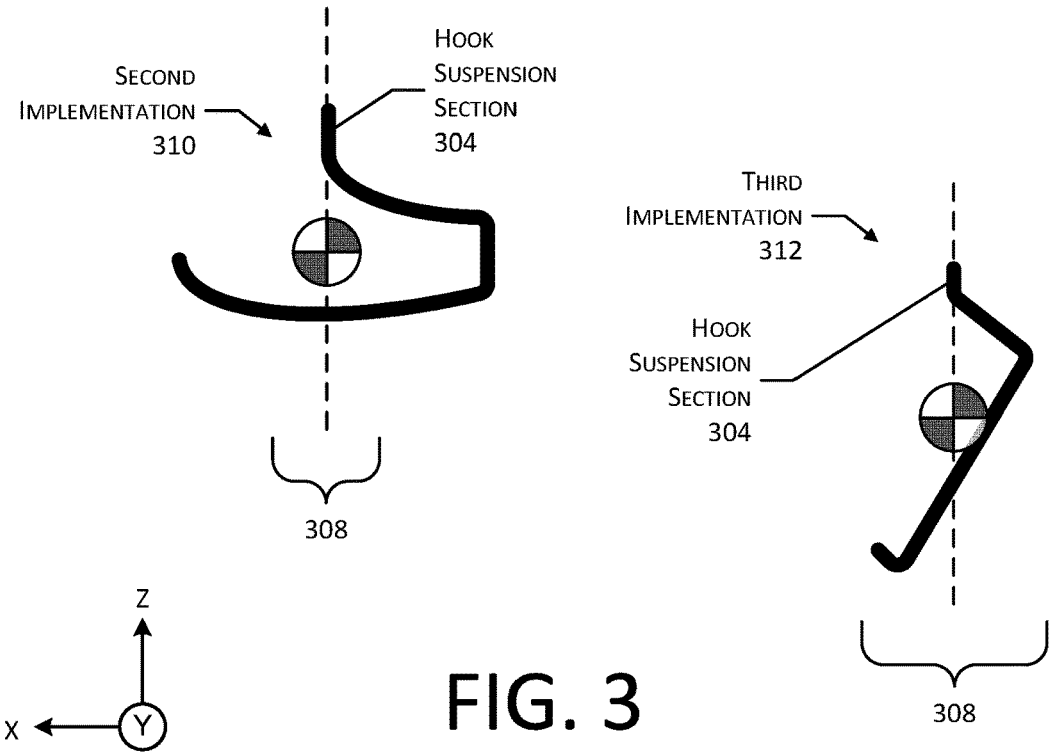

SECOND
IMPLEMENTATION
310
HOOK
SUSPENSION
SECTION
304
308
THIRD
IMPLEMENTATION
312
HOOK
SUSPENSION
SECTION
304
308
Z
X
Y

FIG. 3

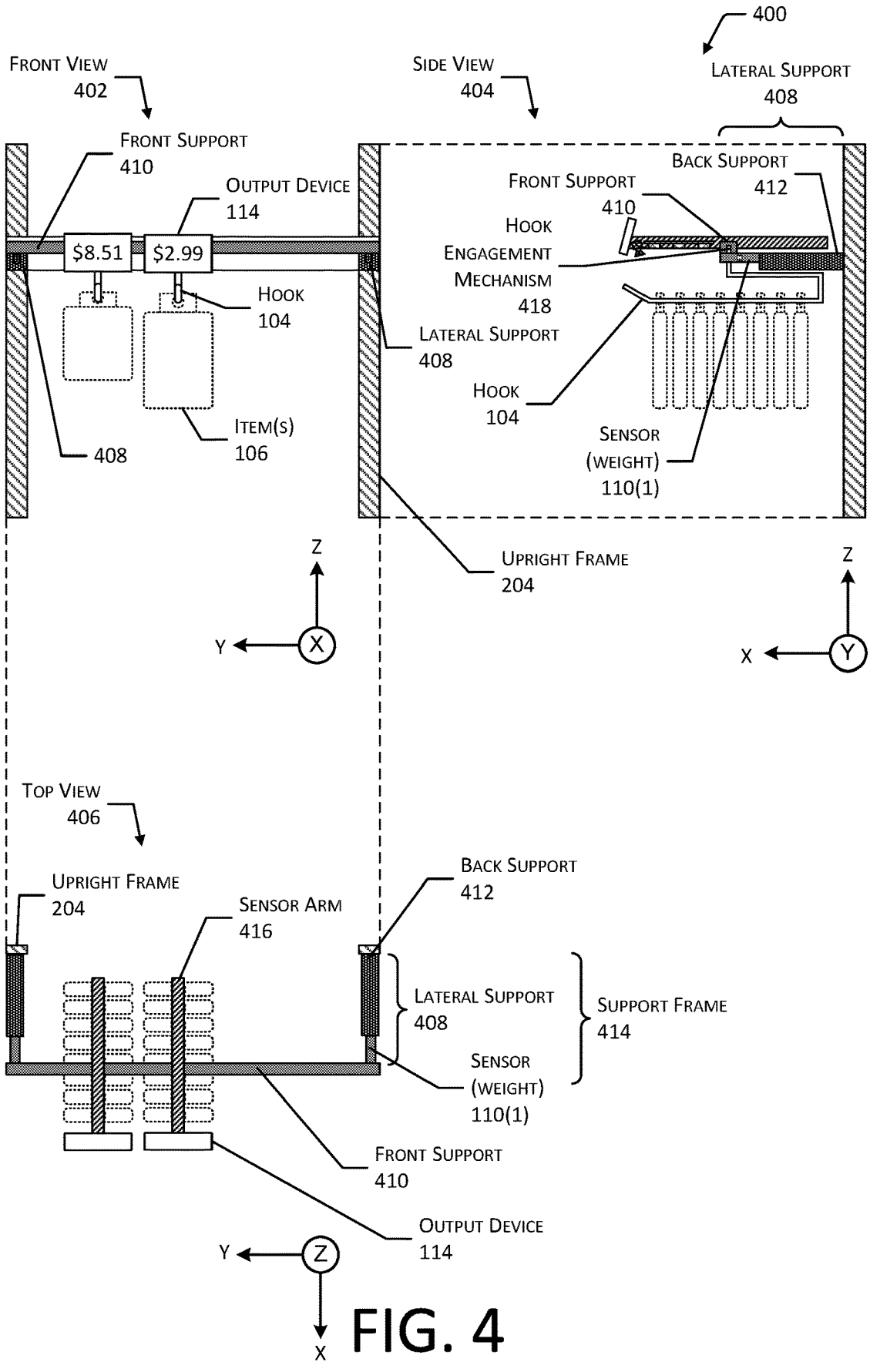

400
FRONT VIEW
402
SIDE VIEW
404
LATERAL SUPPORT
408
FRONT SUPPORT
410
OUTPUT DEVICE
114
$8.51
$2.99
HOOK
104
ITEM(S)
106
408
BACK SUPPORT
412
FRONT SUPPORT
410
HOOK
ENGAGEMENT
MECHANISM
418
LATERAL SUPPORT
408
HOOK
104
SENSOR
(WEIGHT)
110(1)
UPRIGHT FRAME
204
Z
Y
X
Z
X
Y
TOP VIEW
406
UPRIGHT FRAME
204
SENSOR ARM
416
BACK SUPPORT
412
LATERAL SUPPORT
408
SUPPORT FRAME
414
SENSOR
(WEIGHT)
110(1)
FRONT SUPPORT
410
OUTPUT DEVICE
114
Y
Z
X

FIG. 4

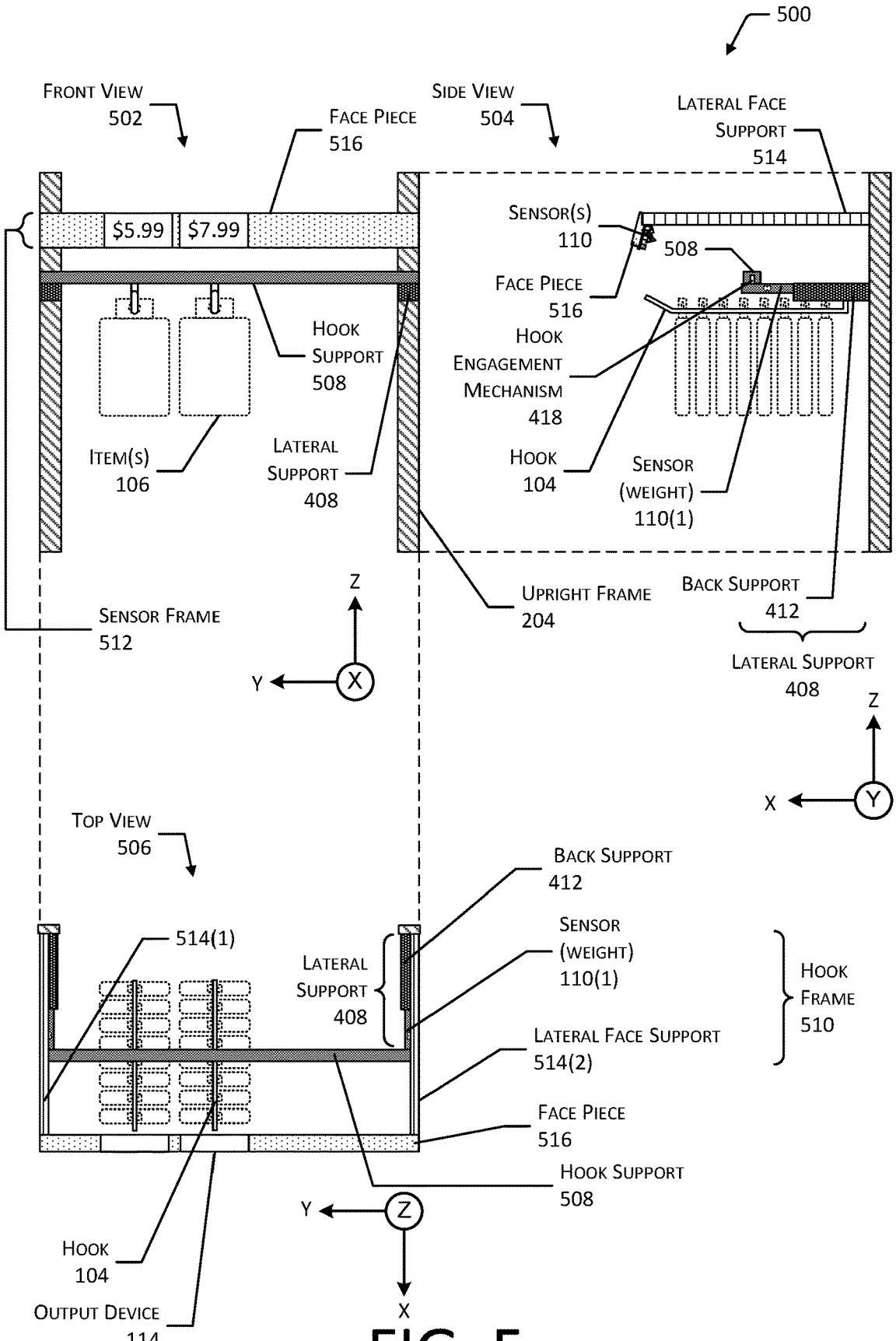

500
FRONT VIEW
502
FACE PIECE
516
SIDE VIEW
504
LATERAL FACE SUPPORT
514
$5.99
$7.99
SENSOR(S)
110
508
FACE PIECE
516
HOOK SUPPORT
508
HOOK ENGAGEMENT MECHANISM
418
ITEM(S)
106
LATERAL SUPPORT
408
HOOK
104
SENSOR (WEIGHT)
110(1)
SENSOR FRAME
512
Z
Y
X
UPRIGHT FRAME
204
BACK SUPPORT
412
LATERAL SUPPORT
408
Z
X
Y
TOP VIEW
506
BACK SUPPORT
412
514(1)
LATERAL SUPPORT
408
SENSOR (WEIGHT)
110(1)
HOOK FRAME
510
LATERAL FACE SUPPORT
514(2)
FACE PIECE
516
HOOK SUPPORT
508
Y
Z
X
HOOK
104
OUTPUT DEVICE
114

FIG. 5

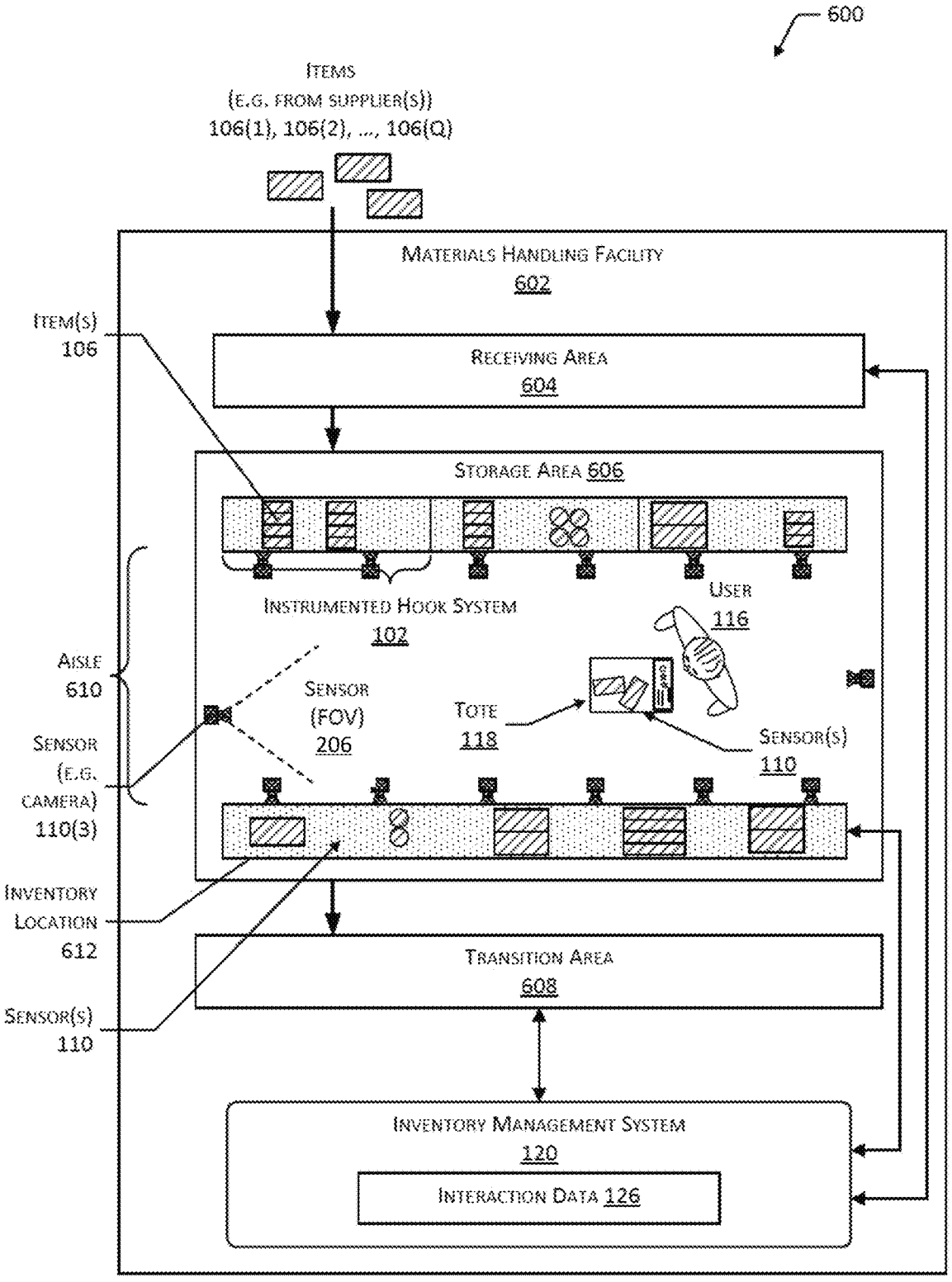

600
ITEMS
(E.G. FROM SUPPLIER(S))
106(1), 106(2), ..., 106(Q)
MATERIALS HANDLING FACILITY
602
ITEM(S)
106
RECEIVING AREA
604
STORAGE AREA 606
INSTRUMENTED HOOK SYSTEM
102
USER
116
AISLE
610
SENSOR
(FOV)
206
TOTE
118
SENSOR(S)
110
SENSOR
(E.G.
CAMERA)
110(3)
INVENTORY
LOCATION
612
TRANSITION AREA
608
SENSOR(S)
110
INVENTORY MANAGEMENT SYSTEM
120
INTERACTION DATA 126

FIG. 6

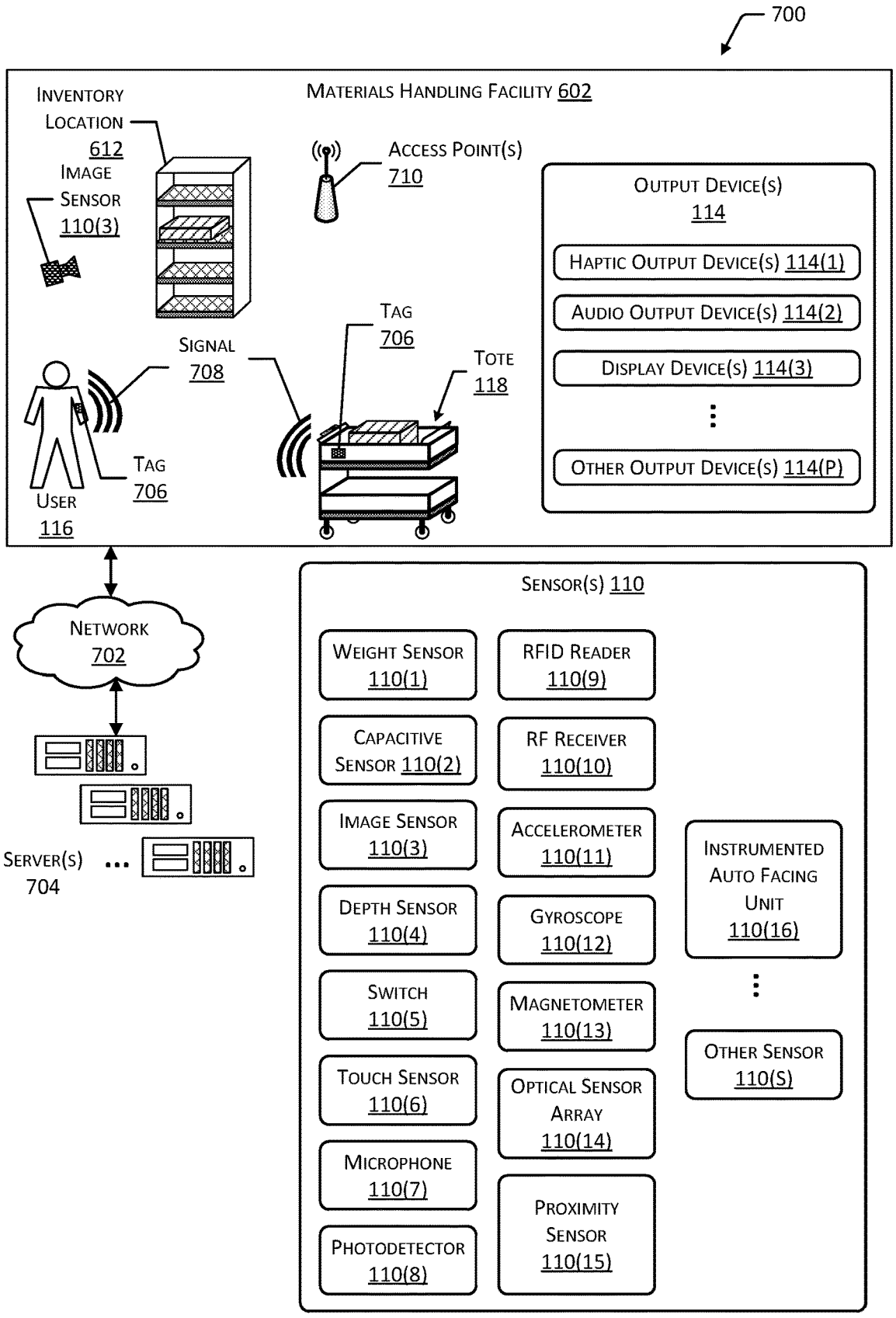

700
MATERIALS HANDLING FACILITY 602
INVENTORY LOCATION 612
IMAGE SENSOR 110(3)
ACCESS POINT(S) 710
OUTPUT DEVICE(S) 114
HAPTIC OUTPUT DEVICE(S) 114(1)
AUDIO OUTPUT DEVICE(S) 114(2)
DISPLAY DEVICE(S) 114(3)
OTHER OUTPUT DEVICE(S) 114(P)
TAG 706
SIGNAL 708
TOTE 118
TAG 706
USER 116
NETWORK 702
SERVER(S) 704
SENSOR(S) 110
WEIGHT SENSOR 110(1)
RFID READER 110(9)
CAPACITIVE SENSOR 110(2)
RF RECEIVER 110(10)
IMAGE SENSOR 110(3)
ACCELEROMETER 110(11)
INSTRUMENTED AUTO FACING UNIT 110(16)
DEPTH SENSOR 110(4)
GYROSCOPE 110(12)
SWITCH 110(5)
MAGNETOMETER 110(13)
TOUCH SENSOR 110(6)
OPTICAL SENSOR ARRAY 110(14)
OTHER SENSOR 110(S)
MICROPHONE 110(7)
PROXIMITY SENSOR 110(15)
PHOTODETECTOR 110(8)

FIG. 7

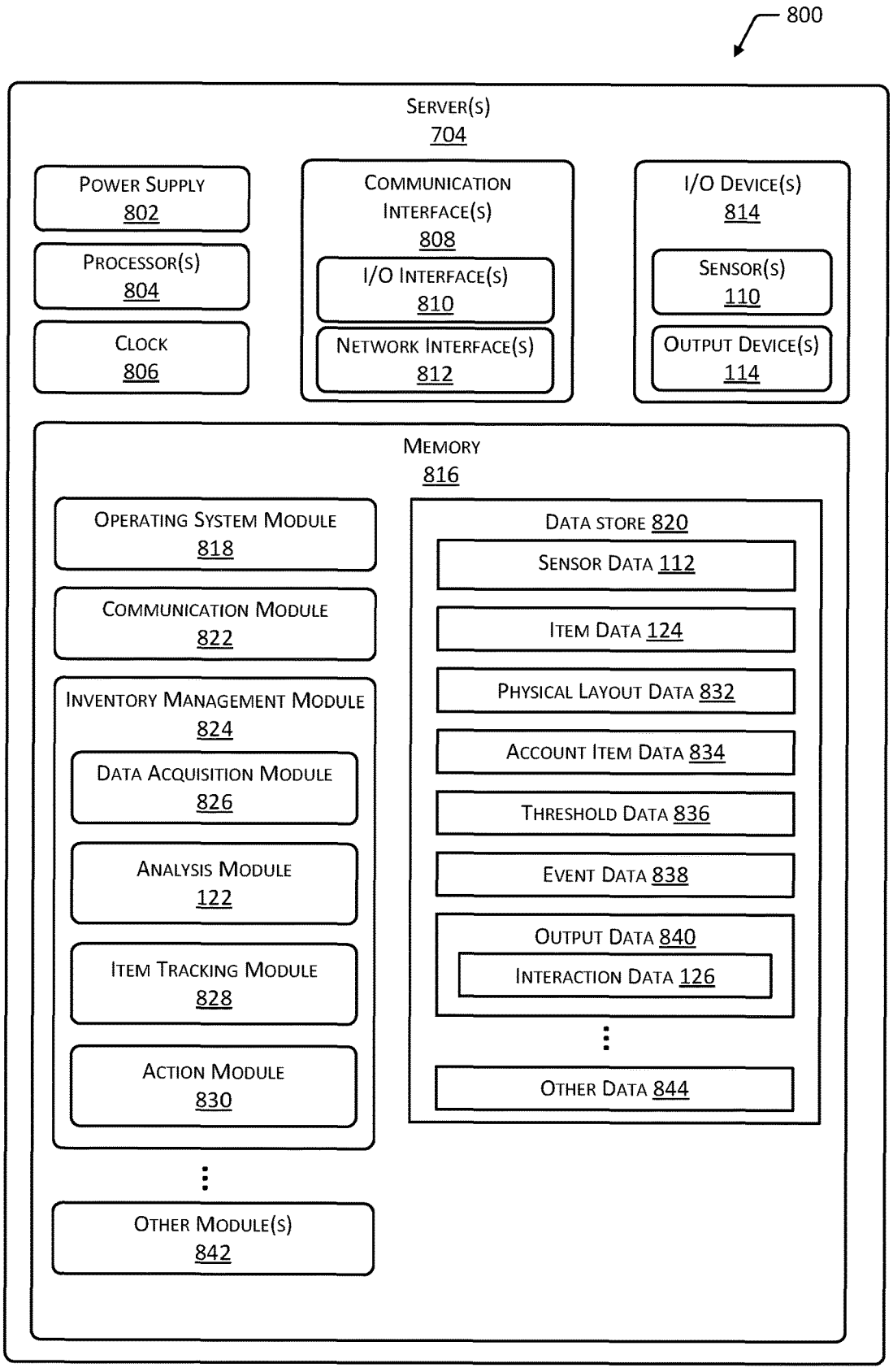

800
SERVER(S)
704
POWER SUPPLY
802
PROCESSOR(S)
804
CLOCK
806
COMMUNICATION INTERFACE(S)
808
I/O INTERFACE(S)
810
NETWORK INTERFACE(S)
812
I/O DEVICE(S)
814
SENSOR(S)
110
OUTPUT DEVICE(S)
114
MEMORY
816
OPERATING SYSTEM MODULE
818
COMMUNICATION MODULE
822
INVENTORY MANAGEMENT MODULE
824
DATA ACQUISITION MODULE
826
ANALYSIS MODULE
122
ITEM TRACKING MODULE
828
ACTION MODULE
830
OTHER MODULE(S)
842
DATA STORE 820
SENSOR DATA 112
ITEM DATA 124
PHYSICAL LAYOUT DATA 832
ACCOUNT ITEM DATA 834
THRESHOLD DATA 836
EVENT DATA 838
OUTPUT DATA 840
INTERACTION DATA 126
OTHER DATA 844

FIG. 8

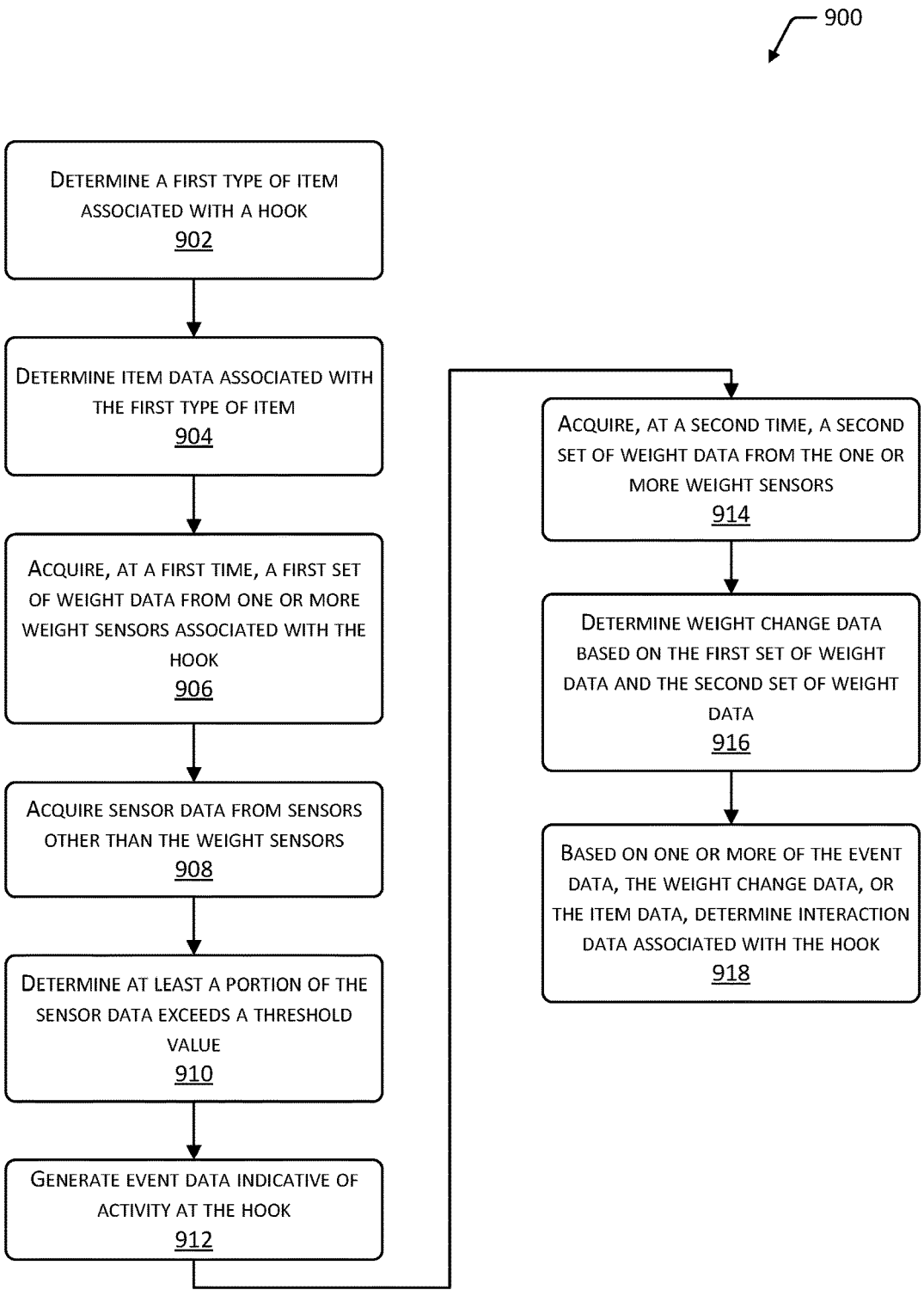

900
DETERMINE A FIRST TYPE OF ITEM ASSOCIATED WITH A HOOK
902
DETERMINE ITEM DATA ASSOCIATED WITH THE FIRST TYPE OF ITEM
904
ACQUIRE, AT A FIRST TIME, A FIRST SET OF WEIGHT DATA FROM ONE OR MORE WEIGHT SENSORS ASSOCIATED WITH THE HOOK
906
ACQUIRE SENSOR DATA FROM SENSORS OTHER THAN THE WEIGHT SENSORS
908
DETERMINE AT LEAST A PORTION OF THE SENSOR DATA EXCEEDS A THRESHOLD VALUE
910
GENERATE EVENT DATA INDICATIVE OF ACTIVITY AT THE HOOK
912
ACQUIRE, AT A SECOND TIME, A SECOND SET OF WEIGHT DATA FROM THE ONE OR MORE WEIGHT SENSORS
914
DETERMINE WEIGHT CHANGE DATA BASED ON THE FIRST SET OF WEIGHT DATA AND THE SECOND SET OF WEIGHT DATA
916
BASED ON ONE OR MORE OF THE EVENT DATA, THE WEIGHT CHANGE DATA, OR THE ITEM DATA, DETERMINE INTERACTION DATA ASSOCIATED WITH THE HOOK
918

FIG. 9

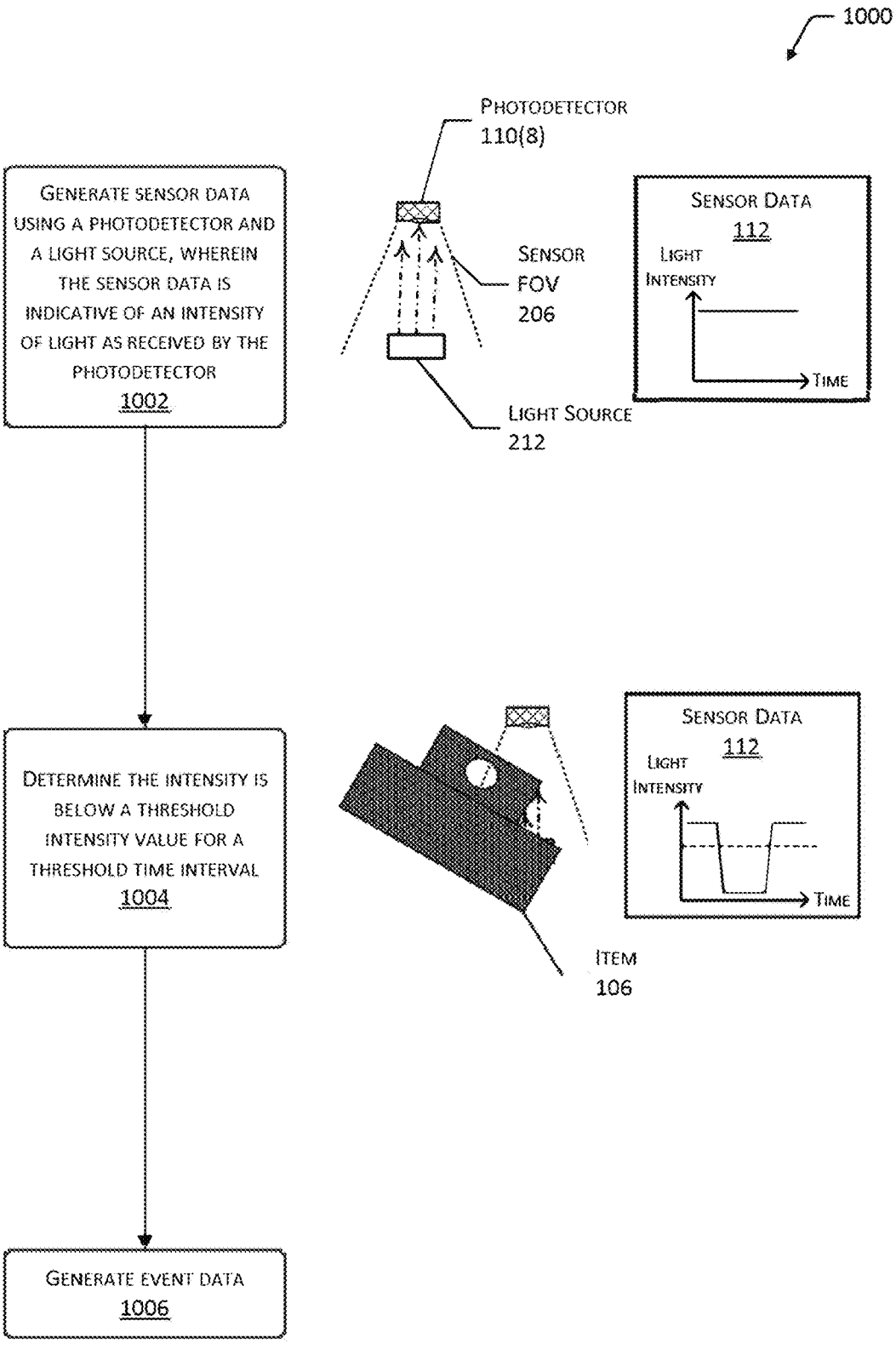

1000
GENERATE SENSOR DATA USING A PHOTODETECTOR AND A LIGHT SOURCE, WHEREIN THE SENSOR DATA IS INDICATIVE OF AN INTENSITY OF LIGHT AS RECEIVED BY THE PHOTODETECTOR
1002
PHOTODETECTOR
110(8)
SENSOR
FOV
206
LIGHT SOURCE
212
SENSOR DATA
112
LIGHT INTENSITY
TIME
DETERMINE THE INTENSITY IS BELOW A THRESHOLD INTENSITY VALUE FOR A THRESHOLD TIME INTERVAL
1004
ITEM
106
SENSOR DATA
112
LIGHT INTENSITY
TIME
GENERATE EVENT DATA
1006

FIG. 10

INSTRUMENTED ITEM HOOK SYSTEM

BACKGROUND

Retailers, wholesalers, and other product distributors typically maintain an inventory of various items that may be ordered, purchased, leased, borrowed, rented, viewed, and so forth, by clients or customers. For example, an e-commerce website may maintain inventory in a fulfillment center. When a customer orders an item, the item is picked from inventory, routed to a packing station, packed, and shipped to the customer. Likewise, physical stores maintain inventory in customer accessible areas, such as in a shopping area, and customers can pick items from inventory and take them to a cashier for purchase, rental, and so forth.

Many physical stores also maintain inventory in a storage area, fulfillment center, or other facility that can be used to replenish inventory located in the shopping areas or to satisfy orders for items that are placed through other channels (e.g., e-commerce). Other examples of entities that maintain facilities holding inventory include libraries, museums, rental centers, and so forth. In each instance, for an item to be moved from one location to another, it is picked from its current location and transitioned to a new location. It is often desirable to monitor quantity or movement of inventory within the facility.

BRIEF DESCRIPTION OF FIGURES

The detailed description is set forth with reference to the accompanying figures. In the figures, the left-most digit(s) of a reference number identifies the figure in which the reference number first appears. The use of the same reference numbers in different figures indicates similar or identical items or features. The figures are not necessarily drawn to scale, and in some figures, the proportions or other aspects may be exaggerated to facilitate comprehension of particular aspects.

FIG. **1** illustrates a system including an instrumented hook system, which includes weight sensors and other sensors to provide sensor data that is used to generate interaction data about inventory, according to some implementations.

FIG. **2** illustrates a side view of an instrumented hook system with sensors integrated into the support arm, according to some implementations.

FIG. **3** illustrates a side view of different hook shapes, according to some implementations.

FIG. **4** illustrates several views of an instrumented hook system using shared weight sensors and instrumented sensor arms, according to some implementations.

FIG. **5** illustrates several views of an instrumented hook system using shared weight sensors and a sensor frame, according to some implementations.

FIG. **6** is a block diagram illustrating a materials handling facility (facility) using the instrumented hook system, according to some implementations.

FIG. **7** is a block diagram illustrating additional details of the facility and sensors, according to some implementations.

FIG. **8** is a block diagram of a server to support operation of the facility, according to some implementations.

FIG. **9** depicts a flow diagram of a process for generating interaction data using an instrumented hook system, according to some implementations.

FIG. **10** depicts a flow diagram of a process for generating event data indicative of removal or addition of an item from a hook using a photodetector and light source, according to some implementations.

While implementations are described herein by way of example, those skilled in the art will recognize that the implementations are not limited to the examples or figures described. It should be understood that the figures and detailed description thereto are not intended to limit implementations to the particular form disclosed but, on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope as defined by the appended claims. The headings used herein are for organizational purposes only and are not meant to be used to limit the scope of the description or the claims. As used throughout this application, the word "may" is used in a permissive sense (i.e., meaning having the potential to), rather than the mandatory sense (i.e., meaning must). Similarly, the words "include," "including," and "includes" mean "including, but not limited to".

DETAILED DESCRIPTION

Described in this disclosure are systems and techniques for generating interaction data at an inventory location, such as in a materials handling facility (facility). The facility may include, or have access to, an inventory management system. The inventory management system may be configured to maintain information about items, users, condition of the facility, and so forth. For example, the inventory management system may maintain data indicative of a number of items at a particular inventory location, what items a particular user is ordered to pick, how many items have been picked or placed at the inventory location, requests for assistance, environmental status of the facility, and so forth.

Operation of the facility may be facilitated by using one or more sensors to acquire information about interactions in the facility. The inventory management system may process the sensor data from the one or more sensors to determine interaction data. The interaction data is indicative of action such as picking or placing an item at a particular inventory location, presence of the user at the inventory location, and so forth. For example, the inventory management system may use the sensor data to generate interaction data that indicates a type of item a user picked from a particular inventory location, quantity of the pick, and so forth.

An inventory location may include shelves, hooks, and so forth, that hold or otherwise support a type of item. Items may be added to (placed) or removed (picked) from the inventory location. In one implementation, the inventory location may comprise an instrumented hook system. Each hook may hold a different type of item and may include one or more sensors. The sensors may include weight sensors, capacitive sensors, image sensors, and so forth. The inventory management system may use the data from these sensors to determine the interaction data.

In one implementation, the instrumented hook system may include a support arm from which a hook is suspended. A weight sensor may be used to measure the weight of the hook and any items that are supported by the hook. The hook may be configured such that a center of mass of the hook when unloaded is directly below a hook suspension section from which the hook is suspended. With this arrangement, weight data that is obtained by the weight sensor is free from a lever arm effect and may be more accurate.

Other sensors may be mounted above the hook, such as on the support arm. The sensors may include capacitive sen-

sors, time-of-flight sensors, image sensors, photodetectors, switches, and so forth. For example, a capacitive sensor may be used to detect the presence of a hand of the user as they add (place) or remove (pick) items from the hook. In another example, an optical time-of-flight sensor may be used to detect the motion or presence of the user's hand while placing or picking items from the hook.

In some implementations, a photodetector or image sensor may be used to detect an occlusion created by the user's hand, or an item as it moves near the hook. For example, a light source such as a light emitting diode may be mounted at the tip of the hook. A photodetector located on the sensor arm above the hook may be configured to detect light emitted from the light source to generate data indicative of intensity. If the intensity of the light detected by the photodetector drops below a threshold value, event data may be generated indicating some activity has taken place with respect to that hook. For example, event data may be generated based on removal of an item hanging on the hook that momentarily occludes the light emitted by the light source.

The event data may be used to trigger or initiate other actions. For example, event data may be produced from the capacitive sensor that indicates a change in capacitance values over time that exceeds a threshold value. Responsive to this event data, weight data may be accessed that was obtained from weight sensors at times corresponding to before and after a time associated with the event data. A change in weight based on the weight data from before and after the time of the event data may be used to determine a quantity of a type of item added to or removed from the inventory location.

By using the techniques described herein, operation of the facility may be improved. Details about interactions between users and items in the facility may be quickly and accurately determined. For example, as items are picked, placed, and so forth, information such as inventory levels based on changes in the count of items at the inventory locations may be readily and more accurately determined. As a result, the inventory management system may be able to quickly track what item a user has interacted with, maintain up-to-date inventory information, and so forth.

Illustrative System

FIG. **1** illustrates a system **100** to generate interaction data about inventory, according to some implementations. Inventory locations may be used to store items. These inventory locations may include, but are not limited to, hooks, shelves, racks, and so forth. Illustrated is an instrumented hook system **102**. The instrumented hook system **102** includes one or more hooks **104**. The hook **104** comprises a structure from which one or more items **106** may be suspended. For example, the hook **104** may comprise a wire, rod, tube, and so forth, made of any number of materials. Each hook **104** may be designated to store some quantity of a particular type of item **106**. For example, a first hook **104**(**1**) may be designated to stow pet treats while a second hook **104**(**2**) may be designated to stow fish food. Hooks **104** may be mounted adjacent to one another, such as side-by-side, one above another, and so forth.

The hook **104** may be suspended from a support arm **108** that is positioned above the hook **104**. In other implementations, the hook **104** may be sufficiently rigid and mounted to a support arm **108** or other structure that is below the items **106**.

The support arm **108** may include one or more sensors **110**. For example, the one or more sensors **110** may include weight sensors **110**(**1**), capacitive sensors **110**(**2**), image sensors **110**(**3**) depth sensors **110**(**4**), switches **110**(**5**), photodetectors **110**(**8**), proximity sensors **110**(**15**), and so forth. One or more weight sensors **110**(**1**) may be configured to determine the weight of a load supported by the hook **104**. For example, the weight sensor **110**(**1**) may comprise a single point load cell that has a first end affixed to the support arm **108** and a second end affixed to a hook suspension section of the hook **104**.

The one or more sensors **110** may be configured to generate sensor data **112**. For example, weight sensors **110**(**1**) may generate weight data **112**(**1**), capacitive sensors **110**(**2**) may generate capacitance data **112**(**2**), image sensors **110**(**3**) may generate image data **112**(**3**), depth sensors **110**(**4**) may generate distance data **112**(**4**), switches **110**(**5**) may generate switch data **112**(**5**), photodetectors **110**(**8**) may generate photodetector data **112**(**6**), proximity sensors **110**(**15**) may generate proximity data **112**(**7**), and so forth. Other configurations of the hook **104**, sensors **110**, and so forth, are discussed below.

The switches **110**(**5**) may include microswitches, pressure switches, momentary switches, and so forth. For example, the switch **110**(**5**) may comprise a D2F model switch with a pin plunger as offered by Omron Corporation of Japan.

In some implementations, the instrumented hook system **102** may include one or more output devices **114**. The output devices **114** are configured to generate output such as displaying colors, text, graphics, icons, sounds, haptic output, scents, and so forth. For example, the output device **114** may comprise an electrophoretic display, a liquid crystal display, a light emitting diode (LED) display, a printed card that is mounted at or near an end of the support arm **108**, and so forth.

A user **116** may interact with the inventory location such as the instrumented hook system **102**. The user **116** may refer to the output device **114** to gather information about the items **106** associated with that output device **114**, about the facility, other information such as advertisements or promotional materials, and so forth. The user **116** may then interact with the instrumented hook system **102**. For example, the user **116** may remove item **106**(**1**) from the hook **104**(**1**) and place the item **106**(**1**) into a tote **118**, or may place the item **106**(**1**) from the tote **118** to the hook **104**(**1**). The tote **118** may be associated with the user **116** or that user's **116** user account.

Each hook **104** may include or be associated with one or more sensors **110**. The sensors **110** may be positioned to gather information about the hook **104** or other type of inventory location. For example, one or more of the sensors **110** may be mounted above the hook **104**, such as being supported by the support arm **108**. The field-of-view of the respective sensors **110** may be directed toward the hook **104**, a portion of the hook **104**, an area in front of or proximate to the hook **104**, and so forth.

In some implementations, one or more of the sensors **110** or portions thereof may be included within or as part of the hook **104**. For example, part of a photodetector system such as a light source or a photodetector **110**(**8**) may be mounted at the tip of the hook **104**.

An inventory management system **120** may access the sensor data **112** generated by the sensors **110**. The inventory management system **120** may be configured to perform various functions such tracking changes to a quantity on hand of the items **106** at the hook **104**.

The inventory management system **120** may include or have access to an analysis module **122**. The analysis module **122** may access information including, but not limited to, item data **124**, sensor data **112**, or other information.

The item data **124** provides information about a particular type of item **106**, including characteristics of that type of item **106** such as physical dimensions, where that type of item **106** is located in the facility, characteristics about how the item **106** appears, capacitance values associated with the type of item **106**, and so forth. The item data **124** may indicate the types and quantities of items **106** that are expected to be stored at that particular inventory location such as at hook **104**, width and depth of that type of item **106**, weight of the type of item **106** individually or in aggregate, sample images of the type of item **106**, and so forth.

The item data **124** may include an item identifier. The item identifier may be used to distinguish one type of item **106** from another. For example, the item identifier may include a stock keeping unit (SKU) string, Universal Product Code (UPC) number, radio frequency identification (RFID) tag data, and so forth. The items **106** that are of the same type may be referred to by the same item identifier. For example, cans of beef flavor Brand X dog food may be represented by the item identifier value of "9811901181". In other implementations, non-fungible items **106** may each be provided with a unique item identifier, allowing each to be distinguished from one another.

The item data **124** may include one or more geometry data, item weight data, sample image data, sample capacitance data, or other data. The geometry data may include information indicative of size and shape of the item **106** in one, two, or three dimensions. For example, the geometry data may include the overall shape of an item **106**, such as a cuboid, sphere, cylinder, and so forth. The geometry data may also include information such as length, width, depth, and so forth, of the item **106**. Dimensional information in the geometry data may be measured in pixels, centimeters, inches, arbitrary units, and so forth. The geometry data may be for a single item **106**, or a package, kit, or other grouping considered to be a single item **106**. The item weight data comprises information indicative of a weight of a single item **106**, or a package, kit, or other grouping considered to be a single item **106**. The item data **124** may include other information. For example, the other information may be indicative of a weight distribution of the item **106**, point cloud data for the item **106**, and so forth.

The sample capacitance data may comprise data indicative of a previously measured or calculated change in capacitance of a representative capacitive sensor **110**(**2**) based on or resulting from the presence or absence of a sample of the type of item **106**. For example, during processing or intake of the item **106** at the facility, a sample of the type of item **106** may be placed on a capacitive sensor **110**(**2**) to generate the sample capacitance data.

The sample image data may comprise one or more images of one or more of that type of item **106**. For example, sample image data may be obtained during processing or intake of the item **106** to be used by the facility.

The item data **124** may include one or more inventory location identifiers (IDs). The inventory location ID is indicative of a particular area or volume of an inventory location such as a hook **104** that is designated for stowage of the type of item **106**. For example, a single rack may have several hooks **104**, each with a different inventory location ID. Each of the different inventory location IDs may be associated with a hook **104** or a lane on a shelf, the lane describing a particular area on the shelf designated for storage of a particular type of item **106**. A single type of item **106** may be associated with a particular inventory location ID, a plurality of inventory location IDs may be associated with the single type of item **106**, more than one type of item **106** may be associated with the particular inventory location ID, and so forth.

The item data **124** may also include quantity data. The quantity data may comprise a count or value indicative of a number of items **106**. The count may be a measured or an estimated value. The quantity data may be associated with a particular inventory location ID, an entire facility, and so forth. For example, the same type of item **106** may be stored at different hooks **104** within the facility. The quantity data may indicate the quantity on hand for each of the different inventory locations.

The analysis module **122** may utilize sensor data **112** such as the weight data **112**(**1**), the capacitance data **112**(**2**), the image data **112**(**3**), as well as the item data **124** and other information to generate interaction data **126**. For example, the analysis module **122** may process the sensor data **112** using one or more machine learning techniques to generate the interaction data **126**. The interaction data **126** is indicative of an action such as picking or placing an item **106** at a particular inventory location, presence of the user **116** at the inventory location, and so forth. By utilizing the interaction data **126**, the inventory management system **120** may maintain accurate information with regard to the inventory held at a particular inventory location, items **106** that have been picked by a particular user **116**, and so forth.

FIG. **2** illustrates a side view **200** of an instrumented hook system **102** with sensors **110** integrated into the support arm **108**, according to some implementations. In this implementation, the support arm **108** is affixed to a base **202**. The base **202** may include one or more mechanical, magnetic, or other fasteners used to affix the base **202** to an upright frame **204**.

Mounted within or affixed to the support arm **108** are one or more sensors **110**. The sensors **110** are depicted with their respective sensor field-of-view (FOV) **206** arranged generally downward toward the hook **104** or a front of the instrumented hook system **102**, such as where the user **116** may be standing during operation.

One or more sensors **110** may be configured with a sensor FOV **206** that is directed toward the hook **104**. The sensors **110** are described in more detail below with regard to FIG. **7**. For example, the one or more sensors **110** may include weight sensors **110**(**1**), capacitive sensors **110**(**2**), image sensors **110**(**3**) depth sensors **110**(**4**), switches **110**(**5**), photodetectors **110**(**8**), proximity sensors **110**(**15**), and so forth.

The weight sensor **110**(**1**) may be used to determine the weight of a load supported by the hook **104**. For example, the weight sensor **110**(**1**) may comprise a load cell that has a first end affixed to the support arm **108** and a second end affixed to a hook suspension section of the hook **104**, such as depicted here. As items **106** are added to or removed from the hook **104**, the weight data **112**(**1**) generated by the weight sensor **110**(**1**) changes. Based at least in part on the weight data **112**(**1**), a quantity on hand may be calculated, a quantity added or removed may be determined, and so forth. In the implementation depicted here, the hook **104** is suspended such that the single weight sensor **110**(**1**) may determine the weight of the hook **104**.

In some implementations, one or more sensors **110** or portions thereof may be incorporated into or supported by the hook **104**. For example, a wire harness **208** may connect electronics within the support arm **108** to a switch **110**(**5**) located proximate to a hook tip **210**. The switch **110**(**5**) may be configured to make or break an electrical contact responsive to the passage of an item **106** to or from a portion of the hook **104**. For example, a portion of the item **106** may push against the switch **110**(**5**) while it is being removed from the

hook **104**. This push may generate switch data **112**(**5**) that may be indicative of the particular switch **110**(**5**) that was activated, a duration of activation, and so forth.

In another example, the wire harness **208** may connect electronics within the support arm **108** to a light source **212** located proximate to the hook tip **210**. The light source **212** may be configured to emit light that may be detected by the photodetector **110**(**8**) when no obstruction exists between the light source **212** and the photodetector **110**(**8**). As items **106** are added to or removed from the hook **104**, their passage may occlude the emitted light. Photodetector data **112**(**6**) that is indicative of time, duration, intensity of light received, and so forth, may be generated by a processor. For example, the photodetector data **112**(**6**) may indicate that three occlusions took place. Based on these three occlusions, the analysis module **122** may determine that the quantity on hand at the hook **104** changed by a quantity of three. Weight data **112**(**1**) obtained from the weight sensor **110**(**1**) may be used to confirm the quantity, determine whether that quantity was added or removed, and otherwise disambiguate the interaction that took place.

In an alternative implementation, the photodetector **110**(**8**) may be positioned at the hook tip **210**, while the light source **212** is located elsewhere, such as on the support arm **108**. In other implementations, optical waveguides, fiber optics, internal reflection of tubes, and so forth, may be used to direct the light to or from different portions of the apparatus. For example, the photodetector **110**(**8**) and the light source **212** may both be located within the support arm **108**, and one or more optical fibers may be used to direct emitted light to a particular exit point and to direct received light for a particular ingress point. In some implementations, the light source **212** as detected by the photodetector **110**(**8**) may be an ambient or room light.

The sensor data **112** may be used to generate event data that is indicative of some activity occurring with respect to the hook **104**. For example, capacitance data **112**(**2**) from the capacitive sensor **110**(**2**) may detect the presence of a hand of the user **116** at the hook **104**. Based on this detection, event data indicative of a change at the hook **104** may be generated. Responsive to the event data, other sensor data **112** corresponding to one or more of times before, during, or after the detection may be acquired or accessed. Continuing the example, the event data may be indicative of a presence of a hand at a particular hook **104** at a particular time. The weight data **112**(**1**) from before and after the event indicated by the event data may be processed to determine a weight change.

Different combinations of sensors **110** and the placement thereof with respect to the hook **104** may vary. For example, in some implementations, the depth sensor **110**(**4**) may be located proximate to a support arm tip **214** or a front end of the support arm **108**, such that the sensor FOV **206** includes a potential location where the user **116** may stand during use. In other implementations, such as described below with regard to FIGS. **4** and **5**, weight sensors **110**(**1**) may be used to obtain weight data **112**(**1**) from a plurality of hooks **104**, sensors **110** may be located on the sensor frame above and separate from the hooks **104**, and so forth.

One or more output devices **114** may be mounted on a front of the support arm **108**. In some implementations, the output device **114** or structures associated with the output device **114** may be used to conceal one or more of the sensors **110**.

FIG. **3** illustrates a side view **300** of different hook shapes, according to some implementations. In the first implementation **302**, the hook **104** is depicted. The hook **104** includes a hook suspension section **304**. The hook suspension section **304** comprises a mechanical fitting, feature, or portion of the hook **104** that may be used to support the hook **104** and a load carried by the hook **104**.

The hook **104** may be shaped, constructed, or otherwise configured to exhibit a hook center of mass **306** that is positioned within a center of mass tolerance distance **308** beneath the hook suspension section **304** during normal use. The hook center of mass **306** may be considered a point relative to the hook **104** at which a weighted relative position of mass as distributed through the hook **104** sums to zero. For example, the hook center of mass **306** may comprise a point at which an applied force causes the hook **104** to move without rotation. The hook center of mass **306** may be within a body of the hook **104** or may be external to the hook **104**. For example, as shown in FIG. **3**, the hook center of mass **306** is depicted as occurring within free space of an interior of a curve formed by the hook **104**.

The center of mass tolerance distance **308** comprises a distance that the hook center of mass **306** may deviate from the hook suspension section **304** without adversely affecting operation of the weight sensor **110**(**1**). For example, when the hook suspension section **304** of the hook **104** is affixed to a first end of a load cell in a weight sensor **110**(**1**) and the hook center of mass **306** is within the center of mass tolerance distance **308**, the torque (or lever arm) applied to the first end of the load cell is within the operational specification of the load cell. The weight data **112**(**1**) resulting from the load cell may then be considered accurate and not adversely skewed by excessive torque. The center of mass tolerance distance **308** may comprise a horizontal distance between a vertical line extending from a center point of the hook suspension section **304** and a vertical line extending through a center of the hook center of mass **306**.

For example, as depicted in the first implementation **302**, the hook **104** may describe a "C" shape that includes three approximately right angle corners. In some implementations, the hook tip **210** may extend at an angle relative to another portion of the hook **104**. For example, the hook tip **210** may be bent slightly upwards.

The center of mass tolerance distance **308** may differ based on different types of weight sensors **110**(**1**) that are in use. For example, a first model of weight sensor **110**(**1**) may have a center of mass tolerance distance **308** of 10 cm, while a second model of weight sensor **110**(**1**) may have a center of mass tolerance distance **308** of 25 cm.

Other possible configurations of the hook **104** may be used. For example, a second implementation **310** and a third implementation **312** are also depicted. As described above, the hook center of mass **306** for each hook **104** is located within the center of mass tolerance distance **308** beneath their respective hook suspension sections **304**.

The hook **104** may comprise materials that are bent, stamped, formed, forged, deposited, hardened, machined, and so forth. For example, the hook **104** may comprise one or more of metal wire, tubing, plastic, and so forth. The hook **104** may include one or more arcuate sections, with each arcuate section having a different radius of curvature.

FIG. **4** illustrates several views **400** of an instrumented hook system **102** using shared weight sensors **110**(**1**) and instrumented sensor arms, according to some implementations. In this illustration, a front view **402**, a side view **404**, and a top view **406** are depicted.

In the front view **402**, a pair of lateral supports **408** is depicted. Each of the lateral supports **408** may be affixed to an upright frame **204**. Each of the lateral supports **408** may include a back support **412** and one or more weight sensors

110(1). The back support **412** may include one or more mechanical engagement features such as pegs that are configured to engage corresponding mechanical engagement features such as holes in the upright frame **204**. A first end of the weight sensor **110**(**1**) is affixed to or supported by the back support **412**.

A front support **410** located distal to the upright frame **204** extends from a left lateral support **408** to a right lateral support **408**. The front support **410** is supported at least in part by a second end of the weight sensors **110**(**1**) that are part of the lateral supports **408**. As a result, the weight sensors **110**(**1**) are able to determine the load supported by the front support **410**. The subassembly that includes the lateral supports **408** and the front support **410** may be designated as a support frame **414**. The support frame **414** may support any number of sensor arms **416**, hooks **104**, and so forth.

The front support **410** may include one or more fastening features that are used to affix a portion of a sensor arm **416** to the front support **410**. The fastening features may include mechanical engagement features, magnets, and so forth. For example, the sensor arm **416** may include a tab that engages a slot in the front support **410**. The front support **410** may also include one or more hook engagement mechanisms **418** to mechanically engage one or more of the hook suspension sections **304** of the hooks **104**. The hook engagement mechanism **418** may include a slot, bolt, screw, aperture, and so forth, that engages with one or more elements of the hook suspension section **304**. For example, the hook engagement mechanism **418** may comprise an aperture into which the upper section of the hook suspension section **304** of the hook **104** is inserted and then retained using a set screw.

The sensor arm **416** may be affixed to the support frame **414**. The front support **410** and the sensor arm **416** may be substantially perpendicular to one another in some implementations. The sensor arm **416** may include one or more of the sensors **110**, such as described above. The hook **104** may be supported from one or more of the sensor arm **416** or the front support **410**. The weight sensors **110**(**1**) in the lateral supports **408** obtain weight data **112**(**1**) associated with all of the hooks **104** that are supported by the support frame **414**.

As a load supported by the hook **104** changes, the weight as measured by the weight sensors **110**(**1**) in the lateral supports **408** may increase or decrease. By summing the weight data **112**(**1**) obtained from the weight sensors **110**(**1**) at all of the lateral supports **408**, a total weight at an instant in time may be determined. Weight data **112**(**1**) may be associated with a particular hook **104** based on sensor data **112** obtained from the other sensors **110**, such as on the sensor arm **416**. For example, output from the capacitive sensor **110**(**2**) indicative of proximity of an object may be used to generate event data associated with hook **104**(**1**). Based on the event data, subsequent change in the weight as measured by the weight sensors **110**(**1**) at the lateral supports **408** may be associated with a first hook **104**(**1**), instead of a second hook **104**(**2**) on the same support frame **414**.

A single support frame **414** may be used to support a plurality of hooks **104**, sensor arms **416**, and so forth. In some implementations, each hook **104** may have an associated sensor arm **416**. In other implementations, a single sensor arm **416** may provide sensor data **112** for a plurality of hooks **104**.

In some implementations, instead of, or in addition to, the use of hooks **104**, a pegboard or similar structure may be supported by, or used in place of, the front support **410**. The pegboard may comprise a series of holes or other mechanical engagement features. Hooks **104** or other support devices for holding items **106** may then be affixed to the pegboard.

FIG. **5** illustrates several views **500** of an instrumented hook system **102** using shared weight sensors **110**(**1**) and a separate sensor frame, according to some implementations. In this illustration, a front view **502**, a side view **504**, and a top view **506** are depicted.

In the front view **502**, a pair of lateral supports **408** are depicted. Each of the lateral supports **408** may be affixed to an upright frame **204**. As described above, each lateral support **408** may include a back support **412** with one or more mechanical engagement features such as pegs configured to engage corresponding mechanical engagement features such as holes in the upright frame **204**. Each of the lateral supports **408** may also include one or more weight sensors **110**(**1**). A first end of the weight sensor **110**(**1**) may be affixed or otherwise mounted to the back support **412**.

A hook support **508** is located distal to the upright frame **204** and extends from a left lateral support **408** to a right lateral support **408**. The hook support **508** may be supported by a second end of the weight sensors **110**(**1**). The subassembly that includes the lateral supports **408** and the hook support **508** may be designated as a hook frame **510**. The hook support **508** may include a hook engagement mechanism **418**, such as one or more fastening features that are used to retain one or more hooks **104**. The fastening features may include mechanical engagement features, magnets, and so forth. For example, the hook engagement mechanism **418** may comprise a series of slots into which the hook suspension section **304** of the hook **104** may be mechanically engaged, allowing the body of the hook **104** to be suspended beneath.

Also depicted is a sensor frame **512** that may include a left lateral face support **514**(**1**), a right lateral face support **514**(**2**), and the face piece **516**. The lateral face supports **514** may each be affixed to a respective upright frame **204**. The sensor frame **512** is configured to support a sensor assembly that includes one or more of the sensors **110**. The sensor frame **512** may be mounted above or below the hook frame **510**. In some implementations, a sensor frame **512** may be mounted between an upper hook frame **510**(**1**) and a lower hook frame **510**(**2**), with sensors **110** arranged with a sensor FOV **206** to cover both hook frames **510**. The sensor frame **512** may also include one or more of the output devices **114**.

In the configuration depicted here, the weight of the items **106**, hooks **104**, hook support **508**, and so forth, is supported by the lateral supports **408**. Weight data **112**(**1**) of the items **106** is determined using the weight sensors **110**(**1**) in the lateral supports **408**. The sensors **110** are supported separately from the upright frame **204** using the lateral face supports **514**.

In one implementation, an image sensor **110**(**3**) may be mounted on a face piece **516**. The image sensor **110**(**3**) may have with a FOV **206** directed generally towards a plurality of the hooks **104**. For example, a rack comprising a plurality of hooks **104** may be viewed by a single camera. In another implementation, the image sensor **110**(**3**) may be mounted to another structure, such as the ceiling overhead.

FIG. **6** is a block diagram **600** illustrating a materials handling facility (facility) **602** using the system **100**, according to some implementations. A facility **602** comprises one or more physical structures or areas within which one or more items **106**(**1**), **106**(**2**), . . . , **106**(Q) may be held. As used in this disclosure, letters in parenthesis such as "(Q)" indicate an integer value greater than or equal to zero. The

items **106** may comprise physical goods, such as books, pharmaceuticals, repair parts, electronic gear, and so forth.

The facility **602** may include one or more areas designated for different functions with regard to inventory handling. In this illustration, the facility **602** includes a receiving area **604**, a storage area **606**, and a transition area **608**.

The receiving area **604** may be configured to accept items **106**, such as from suppliers, for intake into the facility **602**. For example, the receiving area **604** may include a loading dock at which trucks or other freight conveyances unload the items **106**. In some implementations, the items **106** may be processed, such as at the receiving area **604**, to generate at least a portion of the item data **124**. For example, an item **106** may be imaged or otherwise scanned to develop reference images or representations of the item **106** at the receiving area **604**.

The storage area **606** is configured to store the items **106**. The storage area **606** may be arranged in various physical configurations. In one implementation, the storage area **606** may include one or more aisles **610**. The aisle **610** may be configured with, or defined by, inventory locations **612** on one or both sides of the aisle **610**. The inventory locations **612** may include one or more of a hook **104**, a shelf, a rack, a case, a cabinet, a bin, a floor location, or other suitable storage mechanisms for holding, supporting, or storing the items **106**. For example, the inventory locations **612** may comprise racks with hooks **104** or shelves with lanes designated therein. The inventory locations **612** may be affixed to the floor or another portion of the structure of the facility **602**. The inventory locations **612** may also be movable such that the arrangements of aisles **610** may be reconfigurable. In some implementations, the inventory locations **612** may be configured to move independently of an outside operator. For example, the inventory locations **612** may comprise a rack with a power source and a motor, operable by a computing device to allow the rack to move from one location within the facility **602** to another.

One or more users **116** and totes **118** or other material handling apparatuses may move within the facility **602**. For example, the user **116** may move about within the facility **602** to pick or place the items **106** in various inventory locations **612**, placing them on the tote **118** for ease of transport. The tote **118** is configured to carry or otherwise transport one or more items **106**. For example, the tote **118** may include a basket, cart, bag, bin, and so forth. In other implementations, other material handling apparatuses such as robots, forklifts, cranes, aerial drones, and so forth, may move about the facility **602** picking, placing, or otherwise moving the items **106**. For example, a robot may pick an item **106** from a first inventory location **612**(**1**) and move the item **106** to a second inventory location **612**(**2**).

One or more sensors **110** may be configured to acquire information in the facility **602**. The sensors **110** may include, but are not limited to, weight sensors **110**(**1**), capacitive sensors **110**(**2**), image sensors **110**(**3**), depth sensors **110**(**4**), and so forth. The sensors **110** may be stationary or mobile, relative to the facility **602**. For example, the inventory locations **612** may contain weight sensors **110**(**1**) to acquire weight data **112**(**1**) of items **106** stowed therein, image sensors **110**(**3**) to acquire images of picking or placement of items **106** on hooks **104**, optical sensor arrays **110**(**14**) to detect shadows of the user's **116** hands at the inventory locations **612**, and so forth. In another example, the facility **602** may include image sensors **110**(**3**) to obtain images of the user **116** or other objects in the facility **602**. The sensors **110** are discussed in more detail below with regard to FIG. **7**.

While the storage area **606** is depicted as having one or more aisles **610**, inventory locations **612** storing the items **106**, sensors **110**, and so forth, it is understood that the receiving area **604**, the transition area **608**, or other areas of the facility **602** may be similarly equipped. Furthermore, the arrangement of the various areas within the facility **602** is depicted functionally rather than schematically. For example, in some implementations, multiple different receiving areas **604**, storage areas **606**, and transition areas **608** may be interspersed rather than segregated in the facility **602**.

The facility **602** may include, or be coupled to, the inventory management system **120**. The inventory management system **120** is configured to interact with one or more of the users **116** or devices such as sensors **110**, robots, material handling equipment, computing devices, and so forth, in one or more of the receiving area **604**, the storage area **606**, or the transition area **608**.

The inventory management system **120** or other systems may use the sensor data **112** to track the location of objects within the facility **602**, movement of the objects, or provide other functionality. Objects may include, but are not limited to, items **106**, users **116**, totes **118**, and so forth. For example, a series of images acquired by the image sensor **110**(**3**) may indicate removal by the user **116** of an item **106** from a particular location on the inventory location **612** and placement of the item **106** on or at least partially within the tote **118**.

The facility **602** may be configured to receive different kinds of items **106** from various suppliers and to store them until a customer orders or retrieves one or more of the items **106**. A general flow of items **106** through the facility **602** is indicated by the arrows of FIG. **6**. Specifically, as illustrated in this example, items **106** may be received from one or more suppliers, such as manufacturers, distributors, wholesalers, and so forth, at the receiving area **604**. In various implementations, the items **106** may include merchandise, commodities, perishables, or any suitable type of item **106**, depending on the nature of the enterprise that operates the facility **602**.

Upon being received from a supplier at the receiving area **604**, the items **106** may be prepared for storage in the storage area **606**. For example, in some implementations, items **106** may be unpacked or otherwise rearranged. The inventory management system **120** may include one or more software applications executing on a computer system to provide inventory management functions. These inventory management functions may include maintaining information indicative of the type, quantity, condition, cost, location, weight, or any other suitable parameters with respect to the items **106**. The items **106** may be stocked, managed, or dispensed in terms of countable units, individual units, or multiple units, such as packages, cartons, crates, pallets, or other suitable aggregations. Alternatively, some items **106**, such as bulk products, commodities, and so forth, may be stored in continuous or arbitrarily divisible amounts that may not be inherently organized into countable units. Such items **106** may be managed in terms of a measurable quantity such as units of length, area, volume, weight, time, duration, or other dimensional properties characterized by units of measurement. Generally speaking, a quantity of an item **106** may refer to either a countable number of individual or aggregate units of an item **106** or a measurable amount of an item **106**, as appropriate.

After arriving through the receiving area **604**, items **106** may be stored within the storage area **606**. In some implementations, like items **106** may be stored or displayed

together in the inventory locations **612** such as in bins, on hooks **104**, on shelves, and so forth. In such an implementation, all items **106** of a given kind are stored in one inventory location **612**. In other implementations, like items **106** may be stored in different inventory locations **612**. For example, to optimize retrieval of certain items **106** having frequent turnover within a large physical facility **602**, those items **106** may be stored in several different inventory locations **612** to reduce congestion that might occur at a single inventory location **612**.

When a customer order specifying one or more items **106** is received, or as a user **116** progresses through the facility **602**, the corresponding items **106** may be selected or "picked" from the inventory locations **612** containing those items **106**. In various implementations, item picking may range from manual to completely automated picking. For example, in one implementation, a user **116** may have a list of items **106** they desire and may progress through the facility **602** picking items **106** from inventory locations **612** within the storage area **606** and placing those items **106** into a tote **118**. In other implementations, employees of the facility **602** may pick items **106** using written or electronic pick lists derived from customer orders. These picked items **106** may be placed into the tote **118** as the employee progresses through the facility **602**.

After items **106** have been picked, the items **106** may be processed at a transition area **608**. The transition area **608** may be any designated area within the facility **602** where items **106** are transitioned from one location to another or from one entity to another. For example, the transition area **608** may be a packing station within the facility **602**. When the item **106** arrives at the transition area **608**, the item **106** may be transitioned from the storage area **606** to the packing station. Information about the transition may be maintained by the inventory management system **120**.

In another example, if the items **106** are departing the facility **602**, a list of the items **106** may be obtained and used by the inventory management system **120** to transition responsibility for, or custody of, the items **106** from the facility **602** to another entity. For example, a carrier may accept the items **106** for transport with that carrier accepting responsibility for the items **106** indicated in the list. In another example, a user **116** may purchase or rent the items **106** and remove the items **106** from the facility **602**. During use of the facility **602**, the user **116** may move about the facility **602** to perform various tasks, such as picking or placing the items **106** in the inventory locations **612**.

The interaction data **126** may provide information about an interaction, such as a pick of an item **106** from the inventory location **612**, a place of an item **106** to the inventory location **612**, a touch made to an item **106** at the inventory location **612**, a gesture associated with an item **106** at the inventory location **612**, and so forth. The interaction data **126** may include one or more of the type of interaction, interaction location identifier indicative of where at the inventory location **612** the interaction took place, item identifier, quantity change to the item **106**, user identifier, and so forth. The interaction data **126** may then be used to further update the item data **124**. For example, the quantity of items **106** on hand at a particular hook **104** may be changed based on an interaction that picks or places one or more items **106** at an inventory location **612**.

The inventory management system **120** may combine or otherwise utilize different types of data from different types of sensors **110**. For example, weight data **112(1)** obtained from weight sensors **110(1)** at the inventory location **612** may be used instead of, or in conjunction with, one or more of the capacitance data **112(2)** to determine the interaction data **126**.

FIG. **7** is a block diagram **700** illustrating additional details of the facility **602**, according to some implementations. The facility **602** may be connected to one or more networks **702**, which in turn connect to one or more servers **704**. The network **702** may include private networks such as an institutional or personal intranet, public networks such as the Internet, or a combination thereof. The network **702** may utilize wired technologies (e.g., wires, fiber optic cables, and so forth), wireless technologies (e.g., radio frequency, infrared, acoustic, optical, and so forth), or other connection technologies. The network **702** is representative of any type of communication network, including one or more of data networks or voice networks. The network **702** may be implemented using wired infrastructure (e.g., copper cable, fiber optic cable, and so forth), a wireless infrastructure (e.g., cellular, microwave, satellite, and so forth), or other connection technologies.

The servers **704** may be configured to execute one or more modules or software applications associated with the inventory management system **120** or other systems. While the servers **704** are illustrated as being in a location outside of the facility **602**, in other implementations, at least a portion of the servers **704** may be located at the facility **602**. The servers **704** are discussed in more detail below with regard to FIG. **8**.

The users **116**, the totes **118**, or other objects in the facility **602** may be equipped with one or more tags **706**. The tags **706** may be configured to emit a signal **708**. In one implementation, the tag **706** may be a radio frequency identification (RFID) tag **706** configured to emit a RF signal **708** upon activation by an external signal. For example, the external signal may comprise a radio frequency signal or a magnetic field configured to energize or activate the RFID tag **706**. In another implementation, the tag **706** may comprise a transmitter and a power source configured to power the transmitter. For example, the tag **706** may comprise a Bluetooth Low Energy (BLE) transmitter and battery. In other implementations, the tag **706** may use other techniques to indicate presence of the tag **706**. For example, an acoustic tag **706** may be configured to generate an ultrasonic signal **708**, which is detected by corresponding acoustic receivers. In yet another implementation, the tag **706** may be configured to emit an optical signal **708**.

The inventory management system **120** may be configured to use the tags **706** for one or more of identification of the object, determining a location of the object, and so forth. For example, the users **116** may wear tags **706**, the totes **118** may have tags **706** affixed, and so forth, which may be read and, based at least in part on signal strength, used to determine identity and location.

Generally, the inventory management system **120** or other systems associated with the facility **602** may include any number and combination of input components, output components, and servers **704**.

The one or more sensors **110** may be arranged at one or more locations within the facility **602**. For example, the sensors **110** may be mounted on or within a floor, wall, at a ceiling, at an inventory location **612**, on a tote **118**, may be carried or worn by a user **116**, and so forth.

The sensors **110** may include one or more weight sensors **110(1)** that are configured to measure the weight of a load, such as the item **106**, the tote **118**, or other objects. The weight sensors **110(1)** may be configured to measure the weight of the load at one or more of the inventory locations

612, the tote 118, on the floor of the facility 602, and so forth. For example, the inventory location 612 may include a plurality of hooks 104, lanes, or platforms, with one or more weight sensors 110(1) to provide weight data 112(1) about an individual hook 104, lane, or platform. The weight sensors 110(1) may include one or more sensing mechanisms to determine the weight of a load. These sensing mechanisms may include piezoresistive devices, piezoelectric devices, capacitive devices, electromagnetic devices, optical devices, potentiometric devices, microelectromechanical devices, and so forth. The sensing mechanisms of weight sensors 110(1) may operate as transducers that generate one or more signals based on an applied force, such as that of the load due to gravity. For example, the weight sensor 110(1) may comprise a load cell having a strain gauge and a structural member that deforms slightly when weight is applied. By measuring a change in the electrical characteristic of the strain gauge, such as capacitance or resistance, the weight may be determined. In another example, the weight sensor 110(1) may comprise a force sensing resistor (FSR). The FSR may comprise a resilient material that changes one or more electrical characteristics when compressed. For example, the electrical resistance of a particular portion of the FSR may decrease as the particular portion is compressed by an applied mechanical force. The inventory management system 120 may use the data acquired by the weight sensors 110(1) to identify an object, determine a change in the quantity of objects, determine a location of an object, maintain shipping records, and so forth.

The sensors 110 may include capacitive sensors 110(2). Circuitry associated with the capacitive sensor 110(2) generates capacitance data 112(2). The capacitive sensor 110(2) may comprise one or more conductive elements and a capacitive sensor module that includes electronics to determine the capacitance. The capacitive sensors 110(2) may be configured to utilize a far-field capacitance effect. The far-field capacitance effect may be determined by measuring the self-capacitance of the conductive elements, rather than a mutual capacitance. In one implementation, a known charge may be provided to the conductive element, and the resultant voltage may be measured between the conductive element and the ground. A shield comprising an electrical conductor may be arranged along one or more sides of the conductive element. For example, the shield may be separated from the conductive element by an electrical insulator. During operation, the shield may be driven to the same, (or a substantially similar) electrical potential as that provided to the conductive element. As a result of this, a voltage difference that is below a threshold voltage results between the shield and the conductive element. In some implementations, the voltage difference may be zero. The shield in this configuration directs the electric field generally away from the shield. This directionality may be used to prevent erroneous readings for objects on the back side of the conductive element, which may occur in an unshielded configuration. The directionality may also be used to provide a desired sensor FOV 206. In some implementations, a ground plane may be arranged behind the shield, opposite the conductive element. The ground plane may be separated from the shield by an electrical insulator. The ground plane may be connected to an earth ground in some implementations. Proximity of an object to the conductive element or contact by the object with the conductive element affects the charge on the conductive element, producing a change in the resultant voltage that may then be measured and used to determine a capacitance value.

The sensors 110 may include one or more image sensors 110(3). The one or more image sensors 110(3) may include cameras configured to acquire images of a scene. The image sensors 110(3) are configured to detect light in one or more wavelengths including, but not limited to, terahertz, infrared, visible, ultraviolet, and so forth. The image sensors 110(3) may comprise charge coupled devices (CCD), complementary metal oxide semiconductor (CMOS) devices, microbolometers, and so forth. The inventory management system 120 may use image data 112(3) acquired by the image sensors 110(3) during operation of the facility 602. For example, the inventory management system 120 may identify items 106, users 116, totes 118, and so forth, based at least in part on their appearance within the image data 112(3) acquired by the image sensors 110(3). The image sensors 110(3) may be mounted in various locations within the facility 602. For example, image sensors 110(3) may be mounted overhead, on inventory locations 612, may be worn or carried by users 116, may be affixed to totes 118, and so forth.

One or more depth sensors 110(4) may also be included in the sensors 110. The depth sensors 110(4) may be used to acquire distance data 112(4), spatial or three-dimensional (3D) data, and so forth, about objects within a sensor FOV 206. The depth sensors 110(4) may include optical time-of-flight systems, range cameras, lidar systems, sonar systems, radar systems, structured light systems, stereo vision systems, optical interferometry systems, and so forth.

The inventory management system 120 may use the distance data 112(4) acquired by the depth sensors 110(4) to determine a distance to an object, identify an object, determine a location of an object in 3D real space, and so forth. For example, the distance data 112(4) or depth data provided by an optical time-of-flight sensor may indicate the presence of a user's hand near a particular hook 104.

One or more switches 110(5) may be used to acquire information. The switches 110(5) may be used to detect passage of an item 106 on a hook 104, accept input from the user 116, and so forth. The switches 110(5) may comprise mechanical, capacitive, optical, or other mechanisms. For example, the switches 110(5) may comprise mechanical switches configured to accept an applied force from a touch of the item 106 to generate an input signal. The inventory management system 120 may use data from the switches 110(5) to generate event data.

The sensors 110 may include one or more touch sensors 110(6). The touch sensors 110(6) may use resistive, capacitive, surface capacitance, projected capacitance, mutual capacitance, optical, Interpolating Force-Sensitive Resistance (IFSR), or other mechanisms to determine the position of a touch or near-touch. For example, the IFSR may comprise a material configured to change electrical resistance responsive to an applied force. The location within the material of that change in electrical resistance may indicate the position of the touch. The inventory management system 120 may use data from the touch sensors 110(6) to receive information from the user 116. For example, the touch sensor 110(6) may be integrated with the tote 118 to provide a touchscreen with which the user 116 may select from a menu one or more particular items 106 for picking, enter a manual count of items 106 at an inventory location 612, and so forth.

One or more microphones 112(7) may be configured to acquire information indicative of sound present in the environment. In some implementations, arrays of microphones 112(7) may be used. These arrays may implement beamforming techniques to provide for directionality of gain. The

inventory management system **120** may use the one or more microphones **112**(**7**) to acquire information from acoustic tags **706**, accept voice input from the users **116**, determine ambient noise level, and so forth.

The sensors **110** may include one or more photodetectors **110**(**8**). The photodetectors **110**(**8**) may be configured to provide photodetector data **112**(**6**) indicative of one or more of color or intensity of light impinging thereupon. For example, the photodetector **110**(**8**) may comprise a photodiode and associated circuitry configured to generate a signal or data indicative of an incident flux of photons. The photodetectors **110**(**8**) may be sensitive to one or more of infrared light, visible light, or ultraviolet light. For example, the photodetectors **110**(**8**) may be sensitive to infrared light, and infrared light sources such as light emitting diodes (LEDs) may provide illumination. The photodetectors **110**(**8**) may include photodiodes, photoresistors, photovoltaic cells, quantum dot photoconductors, bolometers, pyroelectric infrared detectors, and so forth. For example, the photodetector **110**(**8**) may use germanium photodiodes to detect infrared light.

One or more radio frequency identification (RFID) readers **110**(**9**), near field communication (NFC) systems, and so forth, may be included as sensors **110**. For example, the RFID readers **110**(**9**) may be configured to read the RF tags **706**. Information acquired by the RFID reader **110**(**9**) may be used by the inventory management system **120** to identify an object associated with the RF tag **706** such as the item **106**, the user **116**, the tote **118**, and so forth. For example, based on information from the RFID readers **110**(**9**) detecting the RF tag **706** at different times and RFID readers **110**(**9**) having different locations in the facility **602**, a velocity of the RF tag **706** may be determined.

One or more RF receivers **110**(**10**) may also be included as sensors **110**. In some implementations, the RF receivers **110**(**10**) may be part of transceiver assemblies. The RF receivers **110**(**10**) may be configured to acquire RF signals **708** associated with Wi-Fi, Bluetooth, ZigBee, 4G, 3G, LTE, or other wireless data transmission technologies. The RF receivers **110**(**10**) may provide information associated with data transmitted via radio frequencies, signal strength of RF signals **708**, and so forth. For example, information from the RF receivers **110**(**10**) may be used by the inventory management system **120** to determine a location of an RF source, such as a communication interface onboard the tote **118**.

The sensors **110** may include one or more accelerometers **110**(**11**), which may be worn or carried by the user **116**, mounted to the tote **118**, and so forth. The accelerometers **110**(**11**) may provide information such as the direction and magnitude of an imposed acceleration. Data such as rate of acceleration, determination of changes in direction, speed, and so forth, may be determined using the accelerometers **110**(**11**).

A gyroscope **110**(**12**) may provide information indicative of rotation of an object affixed thereto. For example, the tote **118** or other objects may be equipped with a gyroscope **110**(**12**) to provide data indicative of a change in orientation of the object.

A magnetometer **110**(**13**) may be used to determine an orientation by measuring ambient magnetic fields, such as the terrestrial magnetic field. The magnetometer **110**(**13**) may be worn or carried by the user **116**, mounted to the tote **118**, and so forth. For example, the magnetometer **110**(**13**) mounted to the tote **118** may act as a compass and provide information indicative of which direction the tote **118** is oriented.

An optical sensor array **110**(**14**) may comprise one or more photodetectors **110**(**8**). The photodetectors **110**(**8**) may be arranged in a regular, repeating, or periodic two-dimensional arrangement such as a grid. The optical sensor array **110**(**14**) may generate image data **112**(**3**). For example, the optical sensor array **110**(**14**) may be arranged within or below an inventory location **612** and obtain information about shadows of items **106**, hand of the user **116**, and so forth.

The sensors **110** may include proximity sensors **110**(**15**) used to determine presence of an object, such as the user **116**, the tote **118**, and so forth. The proximity sensors **110**(**15**) may use optical, electrical, ultrasonic, electromagnetic, or other techniques to determine a presence of an object. In some implementations, the proximity sensors **110**(**15**) may use an optical emitter and an optical detector to determine proximity. For example, an optical emitter may emit light, a portion of which may then be reflected by the object back to the optical detector to provide an indication that the object is proximate to the proximity sensor **110**(**15**). In other implementations, the proximity sensors **110**(**15**) may comprise a capacitive proximity sensor **110**(**15**) configured to provide an electrical field and determine a change in electrical capacitance due to presence or absence of an object within the electrical field.

The proximity sensors **110**(**15**) may be configured to provide proximity data **112**(**7**) indicative of one or more of a presence or absence of an object, a distance to the object, or characteristics of the object. An optical proximity sensor **110**(**15**) may use time-of-flight (ToF), structured light, interferometry, or other techniques to generate the distance data **112**(**4**). For example, an optical time-of-flight sensor determines a propagation time (or "round-trip" time) of a pulse of emitted light from an optical emitter or illuminator that is reflected or otherwise returned to an optical detector. By dividing the propagation time in half and multiplying the result by the speed of light in air, the distance to an object may be determined. In another implementation, a structured light pattern may be provided by the optical emitter. A portion of the structured light pattern may then be detected on the object using a sensor **110** such as an image sensor **110**(**3**). Based on an apparent distance between the features of the structured light pattern, the distance to the object may be calculated. Other techniques may also be used to determine distance to the object. In another example, the color of the reflected light may be used to characterize the object, such as skin, clothing, tote **118**, and so forth.

In some implementations, the proximity sensors **110**(**15**) may include the capacitive sensor **110**(**2**), the depth sensor **110**(**4**), and so forth. For example, a change in capacitance values from one time to another as measured by the capacitive sensor **110**(**2**) may be compared to a threshold value and used to determine an object is proximate. In another example, distance data **112**(**4**) obtained from the depth sensor **110**(**4**) may be compared with a threshold value to determine if an object is deemed proximate.

The sensors **110** may also include an instrumented auto-facing unit (IAFU) **112**(**16**). The IAFU **110**(**16**) may comprise a position sensor configured to provide data indicative of displacement of a pusher. As an item **106** is removed from the IAFU **110**(**16**), the pusher moves, such as under the influence of a spring, and pushes the remaining items **106** in the IAFU **110**(**16**) to the front of the inventory location **612**. By using data from the position sensor, and given item data **124** such as a depth of an individual item **106**, a count may be determined, based on a change in position data. For example, if each item **106** is 1 inch deep and the position

data indicates a change of 7 inches, the quantity held by the IAFU **110**(**16**) may have changed by 7 items **106**. This count information may be used to confirm or provide a cross check for a count obtained by other means, such as analysis of the weight data **112**(**1**), the capacitance data **112**(**2**), the image data **112**(**3**), and so forth.

The sensors **110** may include other sensors **110**(S) as well. For example, the other sensors **110**(S) may include light curtains, ultrasonic rangefinders, thermometers, barometric sensors, hygrometers, and so forth. For example, the inventory management system **120** may use information acquired from thermometers and hygrometers in the facility **602** to direct the user **116** to check on delicate items **106** stored in a particular inventory location **612**, which is overheating, too dry, too damp, and so forth.

In one implementation, a light curtain may utilize a linear array of light emitters and a corresponding linear array of light detectors. For example, the light emitters may comprise a line of infrared LEDs or vertical cavity surface emitting lasers (VCSELs) that are arranged above and in front of the inventory location **612**, while the light detectors comprise a line of photodiodes sensitive to infrared light arranged below the light emitters. The light emitters produce a "lightplane" or sheet of infrared light that is then detected by the light detectors. An object passing through the lightplane may decrease the amount of light falling upon the light detectors. For example, the hand of the user **116** crossing this lightplane would prevent at least some of the light from light emitters from reaching a corresponding light detector. As a result, a position of the object along the linear array may be determined that is indicative of a touchpoint. This position may be expressed as touchpoint data, with the touchpoint being indicative of the intersection between the hand of the user **116** and the sheet of infrared light. In some implementations, a pair of light curtains may be arranged at right angles relative to one another to provide two-dimensional touchpoint data indicative of a position of touch in a plane. Input from the light curtain, such as indicating occlusion from a hand of a user **116** may be used to generate event data.

In some implementations, the image sensor **110**(**3**) or other sensors **110**(S) may include hardware processors, memory, and other elements configured to perform various functions. For example, the image sensors **110**(**3**) may be configured to generate image data **112**(**3**), send the image data **112**(**3**) to another device such as the server **704**, and so forth.

The facility **602** may include one or more access points **710** configured to establish one or more wireless networks. The access points **710** may use Wi-Fi, NFC, Bluetooth, or other technologies to establish wireless communications between a device and the network **702**. The wireless networks allow the devices to communicate with one or more of the sensors **110**, the inventory management system **120**, the optical sensor arrays **112**(**14**), the tags **706**, a communication device of the tote **118**, or other devices.

Output devices **114** may also be provided in the facility **602**. The output devices **114** are configured to generate signals, which may be perceived by the user **116** or detected by the sensors **110**. In some implementations, the output devices **114** may be used to provide illumination of the optical sensor array **112**(**14**).

Haptic output devices **114**(**1**) are configured to provide a signal that results in a tactile sensation to the user **116**. The haptic output devices **114**(**1**) may use one or more mechanisms such as electrical stimulation or mechanical displacement to provide the signal. For example, the haptic output devices **114**(**1**) may be configured to generate a modulated electrical signal, which produces an apparent tactile sensation in one or more fingers of the user **116**. In another example, the haptic output devices **114**(**1**) may comprise piezoelectric or rotary motor devices configured to provide a vibration, which may be felt by the user **116**.

One or more audio output devices **114**(**2**) may be configured to provide acoustic output. The acoustic output includes one or more of infrasonic sound, audible sound, or ultrasonic sound. The audio output devices **114**(**2**) may use one or more mechanisms to generate the acoustic output. These mechanisms may include, but are not limited to, the following: voice coils, piezoelectric elements, magnetostrictive elements, electrostatic elements, and so forth. For example, a piezoelectric buzzer or a speaker may be used to provide acoustic output.

The display devices **114**(**3**) may be configured to provide output, which may be seen by the user **116** or detected by a light-sensitive sensor such as an image sensor **110**(**3**) or a photodetector **110**(**8**). In some implementations, the display devices **114**(**3**) may be electronically controlled to produce output in one or more of infrared, visible, or ultraviolet light. The output may be monochrome or in color. The display devices **114**(**3**) may be one or more of emissive, reflective, microelectromechanical, and so forth. An emissive display device **114**(**3**), such as using LEDs, electroluminescent elements, quantum dots, and so forth, is configured to emit light during operation. In comparison, a reflective display device **114**(**3**), such as using an electrophoretic or interferometric element, relies on ambient light to present an image. Backlights or front lights may be used to illuminate non-emissive display devices **114**(**3**) to provide visibility of the output in conditions where the ambient light levels are low. In some implementations, the display devices **114**(**3**) may comprise pre-printed tags, labels, and so forth.

The display devices **114**(**3**) may be located at various points within the facility **602**. For example, the electronically controlled display devices **114**(**3**) may be located on inventory locations **612**, totes **118**, on the floor of the facility **602**, and so forth.

Other output devices **114**(P) may also be present. For example, the other output devices **114**(P) may include scent/odor dispensers, document printers, 3D printers or fabrication equipment, and so forth.

FIG. **8** illustrates a block diagram **800** of a server **704** configured to support operation of the facility **602**, according to some implementations. The server **704** may be physically present at the facility **602**, may be accessible by the network **702**, or a combination of both. The server **704** does not require end-user knowledge of the physical location and configuration of the system that delivers the services. Common expressions associated with the server **704** may include "on-demand computing", "software as a service (SaaS)", "platform computing", "network-accessible platform", "cloud services", "data centers", and so forth. Services provided by the server **704** may be distributed across one or more physical or virtual devices.

One or more power supplies **802** may be configured to provide electrical power suitable for operating the components in the server **704**. The one or more power supplies **802** may comprise batteries, capacitors, fuel cells, photovoltaic cells, wireless power receivers, conductive couplings suitable for attachment to an external power source such as provided by an electric utility, and so forth. The server **704** may include one or more hardware processors **804** (processors) configured to execute one or more stored instructions. The processors **804** may comprise one or more cores. One

or more clocks **806** may provide information indicative of date, time, ticks, and so forth. For example, the processor **804** may use data from the clock **806** to associate a particular interaction with a particular point in time.

The server **704** may include one or more communication interfaces **808** such as input/output (I/O) interfaces **810**, network interfaces **812**, and so forth. The communication interfaces **808** enable the server **704**, or components thereof, to communicate with other devices or components. The communication interfaces **808** may include one or more I/O interfaces **810**. The I/O interfaces **810** may comprise Inter-Integrated Circuit (I2C), Serial Peripheral Interface bus (SPI), Universal Serial Bus (USB) as promulgated by the USB Implementers Forum, RS-232, and so forth.

The I/O interface(s) **810** may couple to one or more I/O devices **814**. The I/O devices **814** may include input devices such as one or more of a sensor **110**, keyboard, mouse, scanner, and so forth. The I/O devices **814** may also include output devices **114** such as one or more of a display device **114(3)**, printer, audio speakers, and so forth. In some embodiments, the I/O devices **814** may be physically incorporated with the server **704** or may be externally placed.

The network interfaces **812** may be configured to provide communications between the server **704** and other devices, such as the totes **118**, routers, access points **710**, and so forth. The network interfaces **812** may include devices configured to couple to personal area networks (PANs), local area networks (LANs), wireless local area networks (WLANS), wide area networks (WANs), and so forth. For example, the network interfaces **812** may include devices compatible with Ethernet, Wi-Fi, Bluetooth, ZigBee, and so forth.

The server **704** may also include one or more busses or other internal communications hardware or software that allow for the transfer of data between the various modules and components of the server **704**.

As shown in FIG. **8**, the server **704** includes one or more memories **816**. The memory **816** may comprise one or more non-transitory computer-readable storage media (CRSM). The CRSM may be any one or more of an electronic storage medium, a magnetic storage medium, an optical storage medium, a quantum storage medium, a mechanical computer storage medium, and so forth. The memory **816** provides storage of computer-readable instructions, data structures, program modules, and other data for the operation of the server **704**. A few example functional modules are shown stored in the memory **816**, although the same functionality may alternatively be implemented in hardware, firmware, or as a system on a chip (SoC).

The memory **816** may include at least one operating system (OS) module **818**. The OS module **818** is configured to manage hardware resource devices such as the I/O interfaces **810**, the I/O devices **814**, the communication interfaces **808**, and provide various services to applications or modules executing on the processors **804**. The OS module **818** may implement a variant of the FreeBSD operating system as promulgated by the FreeBSD Project; other UNIX or UNIX-like variants; a variation of the Linux operating system as promulgated by Linus Torvalds; the Windows operating system from Microsoft Corporation of Redmond, Wash., USA; and so forth.

Also stored in the memory **816** may be a data store **820** and one or more of the following modules. These modules may be executed as foreground applications, background tasks, daemons, and so forth. The data store **820** may use a flat file, database, linked list, tree, executable code, script, or other data structure to store information. In some implementations, the data store **820** or a portion of the data store **820** may be distributed across one or more other devices including the servers **704**, network attached storage devices, and so forth.

A communication module **822** may be configured to establish communications with one or more of the totes **118**, sensors **110**, display devices **114(3)**, other servers **704**, or other devices. The communications may be authenticated, encrypted, and so forth.

The memory **816** may store an inventory management module **824**. The inventory management module **824** is configured to provide the inventory functions as described herein with regard to the inventory management system **120**. For example, the inventory management module **824** may track items **106** between different inventory locations **612**, to and from the totes **118**, and so forth.

The inventory management module **824** may include one or more of a data acquisition module **826**, the analysis module **122**, an item tracking module **828**, an action module **830**, and so forth. The data acquisition module **826** may be configured to acquire and access information associated with operation of the facility **602**. For example, the data acquisition module **826** may acquire sensor data **112** such as the weight data **112(1)**, capacitance data **112(2)**, image data **112(3)**, and so forth. The sensor data **112** may be accessed by the other modules for use.

The analysis module **122** may be configured to use information such as one or more of the sensor data **112**, item data **124**, physical layout data **832**, and so forth, to generate information such as event data **838**, the interaction data **126**, and so forth. The event data **838** may comprise information indicative of a change deemed to be significant that is associated with an inventory location **612** or portion thereof. For example, the event data **838** may be indicative of a determination by a capacitive sensor **110(2)** of proximity of an object, such as an item **106** or user **116**. In another example, the event data **838** may comprise an indication that a weight change has exceeded a threshold value. In yet another example, the event data **838** may indicate that motion between a plurality of images has been detected that exceeds a threshold value. The analysis module **122** may utilize one or more filter functions, comparison functions, and so forth, to determine the event data **838**. For example, the event data **838** may result from a determination that the capacitance data **112(2)** and weight data **112(1)** have each experienced changes that exceed respective threshold values. The analysis module **122** may utilize various rules or conditions to determine the occurrence of an event and subsequent generation of event data **838**.

The analysis module **122** may also accept as input other sensor data **112**, such as input from a photodetector **110(8)**, accelerometer **110(11)**, RF receiver **110(10)**, and so forth. The analysis module **122** may process the sensor data **112** using various techniques. For example, the image data **112(3)** may be processed to generate information indicative of changes between images, object recognition data, and so forth.

Processing of one or more of the image data **112(3)** or portions thereof may be performed by implementing, at least in part, one or more of the following tools or techniques. In one implementation, processing of the image data **112(3)** may be performed, at least in part, using one or more tools available in the OpenCV library as developed by Intel Corporation of Santa Clara, Calif., USA; Willow Garage of Menlo Park, Calif., USA; and Itseez of Nizhny Novgorod, Russia, with information available at www.opencv.org. In another implementation, functions available in the OKAO machine vision library as promulgated by Omron Corpora-

tion of Kyoto, Japan, may be used to process the image data **112**(**3**). In still another implementation, functions such as those in the Machine Vision Toolbox for Matlab (MVTB) available using MATLAB as developed by MathWorks, Inc. of Natick, Mass., USA, may be utilized.

Techniques such as artificial neural networks (ANNs), active appearance models (AAMs), active shape models (ASMs), principal component analysis (PCA), cascade classifiers, and so forth, may also be used to process the sensor data **112** or other data. For example, the ANN may be a trained using a supervised learning algorithm such that object identifiers are associated with images of particular objects within training images provided to the ANN. Once trained, the ANN may be provided with the sensor data **112** and the item data **124** to allow for a determination of similarity between two or more images.

The analysis module **122** may generate the interaction data **126**. The interaction data **126** may include information indicative of a particular inventory location **612** at which some activity has taken place, such as a pick or place of an item **106**. Location information for an interaction may indicate a particular hook **104**, coordinates of the point or area at an inventory location **612** that includes several hooks **104**, and so forth. The interaction may comprise movement, presence, pick, place, and so forth, of an object or an item **106**. For example, a location associated with a pick may be determined by detecting a user **116** with a sensor **110** associated with a particular instrumented hook system **102** at that location. The analysis module **122** may access the item data **124** to determine the type of item **106** stored at the hook **104** and other characteristics about the type of item **106** such as a per item weight. The analysis module **122** may use other modules (not shown) to determine a quantity. For example, weight data **112**(**1**) may be used to determine a weight change value, and this weight change value may be compared with the per item weight to determine a quantity of items **106** that have changed. A sign of the weight change may be used to determine addition or removal of an item **106**. For example, a positive weight change value may indicate an increase in weight indicative of placement of an item **106** at an inventory location **612**, while a negative weight change value may indicate a decrease in the weight indicative of pick of an item **106** from the inventory location **612**. In some implementations, the interaction data **126** may indicate a quantity and type of item **106** that was added or removed from a particular inventory location **612**.

The item tracking module **828** may access physical layout data **832** and generate account item data **834**. The physical layout data **832** may provide information indicative of where sensors **110** and inventory locations **612** are in the facility **602** with respect to one another, FOV **206** of sensors **110** relative to the inventory location **612**, and so forth. For example, the physical layout data **832** may comprise information representative of a map or floor plan of the facility **602** with relative positions of inventory locations **612**, planogram data indicative of how items **106** are to be arranged at the inventory locations **612**, and so forth.

The physical layout data **832** may associate a particular inventory location ID with other information such as physical location data, sensor position data, sensor direction data, sensor identifiers, and so forth. The physical location data provides information about where in the facility **602** objects are, such as the inventory location **612**, the sensors **110**, and so forth. In some implementations, the physical location data may be relative to another object. For example, the physical location data may indicate that a particular weight sensor **110**(**1**), capacitive sensor **110**(**2**), or image sensor **110**(**3**) is associated with the hook **104**(**1**).

The item tracking module **828** may be configured to determine a location within the facility **602**, a user **116**, a user account, and so forth, that is associated with one or more items **106**. For example, the item tracking module **828** may determine that an item **106** has been removed from hook **104**(**1**) and placed into the tote **118**. The item tracking module **828** may then determine the tote **118** is associated with the user **116** or the user account that represents the user **116**. The item tracking module **828** may also use the interaction data **126**. For example, the interaction data **126** indicative of a particular type of item **106** being removed from a particular inventory location **612** may be used as part of the input to track the items **106** that are in the custody of a particular user **116**.

The item tracking module **828** may access information from sensors **110** within the facility **602**, such as those at the instrumented hook system **102** or other inventory locations **612**, onboard the tote **118** or carried by or worn by the user **116**. For example, the item tracking module **828** may receive information from a radio frequency identification (RFID) reader at the inventory location **612** that is indicative of tags associated with each of the items **106** that are placed onto the hook **104**.

The account item data **834** comprises information indicative of one or more items **106** that are within the custody of a particular user **116**, within a particular tote **118**, and so forth. For example, the account item data **834** may comprise a list of the contents of the tote **118**. That list may be further associated with the user account representative of the user **116**. In another example, the account item data **834** may comprise a list of items **106** that the user **116** is carrying. The item tracking module **828** may use the account item data **834** to determine subsets of possible items **106** with which the user **116** may have interacted.

The inventory management module **824**, and modules associated therewith, may access sensor data **112**, threshold data **836**, and so forth. The threshold data **836** may comprise one or more thresholds, ranges, percentages, and so forth, that may be used by the various modules in operation. For example, the analysis module **122** may access threshold data **836** to determine event data **838**.

The inventory management module **824** may generate output data **840**. For example, the output data **840** may include the interaction data **126**, inventory levels for individual types of items **106**, overall inventory, and so forth.

The action module **830** may be configured to initiate or coordinate one or more actions responsive to output data **840**. For example, the action module **830** may access output data **840** that indicates a particular inventory location **612** is empty and in need of restocking. An action such as dispatch of a work order or transmitting instructions to a robot may be performed to facilitate restocking of the location.

In some implementations, the item tracking module **828** may process image data **112**(**3**) using one or more machine vision counting techniques to determine a count of the items **106**. For example, machine vision counting techniques may be configured to recognize a top or front portion of the items **106** in the image data **112**(**3**). This determination may be based on item data **124**, such as previously acquired images of a sampled item **106**. Each of the tops of the type of item **106** appearing in the image data **112**(**3**) may be identified and a count made. A change in count may be determined based on image data **112**(**3**) obtained at a first time and a second time, respectively.

In one implementation, the item tracking module **828** may use one or more algorithms to determine the items **106** in the sensor FOV **206**. For example, a histogram of gradients (HOG) algorithm may be used to extract the features of the items **106**. A state vector machine (SVM) may then be used to classify the extracted features and determine which of the extracted features correspond to items **106**. Output data **840** may be generated that is the resulting count of the items **106** determined by the SVM to be in the image data **112**(**3**).

Other modules **842** may also be present in the memory **816** as well as other data **844** in the data store **820**. For example, the other modules **842** may include an accounting module while the other data **844** may include billing data. The accounting module may be configured to assess charges to accounts associated with particular users **116** or other entities, while the billing data may include information such as payment account numbers.

Illustrative Processes

FIG. **9** depicts a flow diagram **900** of a process for generating interaction data **126** using an instrumented hook system **102**, according to some implementations. The process may be implemented at least in part by one or more of a computing device at the inventory location **612**, by the server **704**, or by another computing device.

At **902**, a first type of item **106** associated with a hook **104** is determined. For example, the item data **124** may be queried to determine the type of item **106** given a particular identifier indicative of a particular hook **104**.

At **904**, item data **124** associated with the first type of item **106** is determined. For example, the weight of an individual item **106** may be retrieved.

At **906**, a first set of weight data **112**(**1**) is acquired, at a first time, from one or more weight sensors **110**(**1**) associated with the hook **104**. For example, the weight data **112**(**1**) for the weight sensors **110**(**1**) on the support arm **108**, support frame **414**, hook frame **510**, and so forth, may be acquired.

At **908**, sensor data **112** from sensors **110** other than the weight sensors **110**(**1**) is obtained. For example, capacitance data **112**(**2**), photodetector data **112**(**6**), proximity data **112**(**7**) and so forth, may be acquired from the sensors **110** that have sensor FOVs **206** that include at least a portion of the hook **104** or the area proximate to the hook **104**.

In another example, the sensor data **112** may include proximity data **112**(**7**) obtained from the proximity sensor **110**(**15**), such as an optical time-of-flight sensor. A first distance may be determined using the proximity sensor **110**(**15**) at a first time. A second distance may be determined using the proximity sensor **110**(**15**) at a second time.

At **910**, at least a portion of the sensor data **112** is determined to exceed a threshold value. The sensor data **112** may be compared by the analysis module **122** to one or more thresholds specified in the threshold data **836**. For example, the capacitance data **112**(**2**) may change beyond a threshold percentage over a specified interval of time. In another example, the second distance of the proximity data **112**(**7**) may be subtracted from the first distance to determine a change in distance.

At **912**, event data **838** indicative of activity at the hook **104** is generated. Continuing the examples above, event data **838** may be generated based on the capacitance data **112**(**2**) changing beyond a threshold percentage over a specified interval of time, the change in distance changing beyond a threshold distance value, and so forth.

In some implementations, the threshold data **836** may include information indicative of a duration or minimum interval of time. For example, a duration of the change in capacitance data **112**(**2**) may need to exceed a minimum interval of time before an event is determined and corresponding event data **838** is generated.

At **914**, a second set of weight data **112**(**1**) is obtained from the one or more weight sensors **110**(**1**) at a second time. In some implementations, acquisition of, or the selection of, the second set of weight data **112**(**1**) may be responsive at least in part to the event data **838**. For example, the acquisition of the second set of weight data **112**(**1**) may be responsive to the change in distance exceeding the distance threshold.

At **916**, weight change data is determined based on the first set of weight data **112**(**1**) and the second set of weight data **112**(**1**). For example, a second total weight calculated from the second set of weight data **112**(**1**) may be subtracted from a first total weight calculated from the first set of weight data **112**(**1**).

At **918**, interaction data **126** associated with the hook **104** is determined based on one or more of the event data **838**, the weight change data, or the item data **124**. For example, the event data **838** may indicate the location of the event, such as at a particular hook **104**, while the weight change data may be divided by the weight of an individual item **106** to determine a change in quantity of items **106** held by the hook **104**. Based on whether the weight change data is a positive or negative number, a determination may be made as to whether the items **106** were added to or removed from the hook **104**. The interaction data **126** may then be indicative of the location of the interaction, the item **106** involved, quantity involved, and so forth.

In some implementations, other techniques may be used to determine interaction data **126**. For example, using the sensor data **112**, a start of an activity associated with the hook **104** may be determined. Continuing the example, using the sensor data **112**, an end of the activity associated with the hook **104** may be determined. Second weight data **112**(**1**) or other sensor data **112** may be acquired using the one or more weight sensors **110**(**1**). Interaction data **126** may then be generated. For example, a weight change value may be generated by subtracting the first set of weight data **112**(**1**) from the second set of weight data **112**(**1**). Based on this weight change value, interaction data **126** indicative of a quantity of items added or removed may be calculated.

In some implementations, one or more of the operations described above may be performed at the instrumented hook system **102**, or by a computing device coupled thereto. For example, several instrumented hook systems **102** located at a particular rack may be connected to a computing device for data processing, communication with the network **702**, and so forth. The computing device may use a communication interface to send the event data **838** and at least a portion of the sensor data **112** to an external device, such as the server **704**.

FIG. **10** depicts a flow diagram **1000** of a process for generating event data **838** indicative of a removal or addition of an item **106** from a hook **104** using a photodetector **110**(**8**) and light source, according to some implementations. The process may be implemented at least in part by one or more of a computing device at the inventory location **612**, by the server **704**, or by another computing device.

At **1002**, sensor data **112** such as the photodetector data **112**(**6**) is generated using a photodetector **110**(**8**) and a light source **212**. The sensor data **112** may be indicative of the intensity of light as received by the photodetector **110**(**8**). As described above with regard to FIG. **2**, the light source **212** and the photodetector **110**(**8**) may be arranged such that

passage of a least a portion of the item **106** to or from the hook **104** results in at least partial occlusion of the emitted light.

At **1004**, the intensity of the light as indicated by the sensor data **112** is determined to be below a threshold intensity value for a threshold time interval. For example, the thresholds may specify a drop in the intensity of more than 20% for a period of time of at least 50 milliseconds.

In other implementations, other analysis of the sensor data **112** may be performed. For example, machine learning techniques may be used to train an ANN or other pattern recognition system to recognize the changes in the photodetector data **112**(**6**) and determine a count, whether items **106** have been added or removed, and so forth.

The light emitted from the photodetector **110**(**8**) may be modulated. Such modulation may reduce interference from other lights sources, improve accuracy of the light intensity readings, and so forth.

At **1006**, event data **838** is generated. Continuing the example, the event data **838** may indicate that a particular number of occlusions of light having the minimum duration specified by the threshold time interval occurred at a particular hook **104** associated with that pairing of a photodetector **110**(**8**) and light source **212**.

Embodiments may be provided as a software program or computer program product including a non-transitory computer-readable storage medium having stored thereon instructions (in compressed or uncompressed form) that may be used to program a computer (or other electronic device) to perform processes or methods described herein. The computer-readable storage medium may be one or more of an electronic storage medium, a magnetic storage medium, an optical storage medium, a quantum storage medium, and so forth. For example, the computer-readable storage media may include, but is not limited to, hard drives, floppy diskettes, optical disks, read-only memories (ROMs), random access memories (RAMs), erasable programmable ROMs (EPROMs), electrically erasable programmable ROMs (EEPROMs), flash memory, magnetic or optical cards, solid-state memory devices, or other types of physical media suitable for storing electronic instructions. Further, embodiments may also be provided as a computer program product including a transitory machine-readable signal (in compressed or uncompressed form). Examples of transitory machine-readable signals, whether modulated using a carrier or unmodulated, include, but are not limited to, signals that a computer system or machine hosting or running a computer program can be configured to access, including signals transferred by one or more networks. For example, the transitory machine-readable signal may comprise transmission of software by the Internet.

Separate instances of these programs can be executed on or distributed across any number of separate computer systems. Thus, although certain steps have been described as being performed by certain devices, software programs, processes, or entities, this need not be the case, and a variety of alternative implementations will be understood by those having ordinary skill in the art.

Additionally, those having ordinary skill in the art will readily recognize that the techniques described above can be utilized in a variety of devices, environments, and situations. Although the subject matter has been described in language specific to structural features or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described. Rather, the specific features and acts are disclosed as illustrative forms of implementing the claims.

What is claimed is:

1. An apparatus comprising:

an upright frame;

a support arm mounted to the upright frame;

a first weight sensor having a first end mounted to the support arm and a second end mounted to a hook suspension section of a hook;

the hook suspended from the second end of the first weight sensor to measure a weight of a load on the hook, the hook suspension section of the hook within a center of mass tolerance distance above a center of mass of the hook; and

a second sensor positioned above a tip of the hook to detect one or more of an object proximate to the hook, addition of an item to the hook, or removal of the item from the hook.

2. The apparatus of claim **1**, wherein the hook suspension section of the hook is within the center of mass tolerance distance above the center of mass of the hook such that a torque applied to the second end of the first weight sensor remains within an operational specification of the first weight sensor.

3. The apparatus of claim **1**, wherein the second sensor comprises an optical time-of-flight sensor including an optical transmitter and an optical receiver; and the apparatus further comprising:

a memory storing computer-executable instructions; and

a hardware processor to execute the computer-executable instructions to:

determine first weight data using the first weight sensor at a first time;

determine a first distance using the second sensor at the first time;

determine a second distance using the second sensor at a second time;

determine a change in distance by subtracting the second distance from the first distance;

determine the change in distance exceeds a threshold value; and

determine second weight data using the first weight sensor at a third time.

4. The apparatus of claim **1**, further comprising:

a light source to emit light proximate to the tip of the hook; and

wherein the second sensor comprises a photodetector to detect at least a portion of the light emitted.

5. The apparatus of claim **1**, wherein the second sensor comprises:

a light source to emit light; and

a photodetector to detect at least a portion of the light emitted as received proximate to the tip of the hook during one or more of the addition or the removal of the item from the hook.

6. The apparatus of claim **1**, wherein the second sensor comprises a switch mounted proximate to the tip of the hook and arranged to one or more of make or break an electrical contact responsive to passage of the item along at least a portion of the hook.

7. The apparatus of claim **1**, further comprising:

a third sensor proximate to the tip of the hook to detect passage of the item along at least a portion of the hook; and

one or more processors to generate sensor data using data from the first weight sensor, the second sensor, and the third sensor.

8. The apparatus of claim **1**, further comprising:

a third sensor proximate to the tip of the hook; and

a wire harness, the wire harness to connect electronics within the support arm to the third sensor.

9. The apparatus of claim **1**, further comprising an output device mounted to the support arm, the output device comprising one or more of:

an electrophoretic display,

a light emitting diode display,

a liquid crystal display, or

a microelectromechanical display; and

further wherein a field-of-view of the second sensor includes at least the tip of the hook.

10. An apparatus comprising:

a support arm;

a weight sensor mounted to the support arm;

a hook suspended from the weight sensor via a first section of the hook, the first section of the hook within a center of mass tolerance distance that is a horizontal distance above a center of mass of the hook;

a second sensor to detect one or more of an object or an item; and

electronics to generate sensor data from the weight sensor and the second sensor.

11. The apparatus of claim **10**, further comprising:

a switch mounted proximate to a tip of the hook and arranged to one or more of make or break an electrical contact responsive to passage of the item along at least a portion of the hook; and

the electronics to generate the sensor data from the weight sensor, the second sensor, and the switch.

12. The apparatus of claim **10**, further comprising:

a light source to emit light from a position on the hook proximate to a tip of the hook;

a photodetector mounted to the support arm between a tip of the support arm and the weight sensor; and

the electronics to generate at least a portion of the sensor data to be indicative of the light emitted from the light source as detected by the photodetector.

13. A system comprising:

a weight sensor;

a hook suspended from the weight sensor via a first section of the hook, the first section of the hook within a center of mass tolerance distance that is a horizontal distance above a center of mass of the hook;

a second sensor to detect one or more of an object or an item;

a memory storing computer-executable instructions; and

one or more hardware processors to execute the computer-executable instructions to:

acquire first data from the weight sensor; and

acquire second data from the second sensor.

14. The system of claim **13**, the one or more hardware processors to further execute the computer-executable instructions to:

determine, using the second data, a start of an activity associated with the hook;

determine, using the second data, an end of the activity associated with the hook;

acquire third data using the weight sensor; and

generate a change value using the first data and the third data.

15. The system of claim **13**, the one or more hardware processors to further execute the computer-executable instructions to:

determine at least a portion of the second data exceeds a threshold value for a minimum interval of time; and

acquire third data using the weight sensor.

16. The system of claim **13**, further comprising a communication interface; and the one or more hardware processors to further execute the computer-executable instructions to:

determine at least a portion of the second data exceeds a threshold value;

generate event data indicative of occurrence of an event at the hook; and

send the event data and at least a portion of the first data to an external device using the communication interface.

17. The system of claim **13**, further comprising:

an upright frame;

a support frame coupled to the upright frame, wherein the weight sensor is coupled to the support frame; and

a sensor arm coupled to the support frame, wherein the hook is suspended from the weight sensor via the sensor arm.

18. The system of claim **13**, further comprising:

an upright frame;

a hook support frame coupled to the upright frame, wherein the weight sensor is coupled to the hook support frame;

a hook support coupled to the hook support frame, wherein the hook is suspended from the weight sensor via the hook support;

a face support frame coupled to the upright frame; and

a face piece coupled to the face support frame, the face piece comprising the second sensor.

19. The system of claim **13**, further comprising:

a light source to emit light from a position on the hook proximate to a tip of the hook;

wherein the second sensor comprises a photodetector proximate to the tip of the hook; and

the one or more hardware processors to further execute the computer-executable instructions to:

determine the second data is indicative of a duration of time during which an intensity of the light emitted from the light source, as received by the photodetector, is below a threshold value; and

based on the second data, generate third data indicative of a change in quantity of items held by the hook.

20. The system of claim **13**, wherein the horizontal distance is between a vertical line extending from a center point of the first section of the hook and a vertical line extending from a center of the center of mass of the hook.

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